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Flow of Water Through Submerged Orifices and Short Tubes with Mouthpieces

Theoretical and Applied Mechanics

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FLOW OF WATER THROUGH SUBMERGED ORIFICES AND SHORT TUBES WITH MOUTHPIECES

BY

FRED B SEELY

B.S. Worcester Polytechnic Institute, 1907

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

IN THEORETICAL AND APPLIED MECHANICS

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

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THE GRADUATE SCHOOL

June 5, 1915.

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY FRED B SEELY

ENTITLED FLOW OF WATER THROUGH SUBMERGED ORIFICES AND SHORT TUBES WITH MOUTHPIECES.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN THEORETICAL AND APPLIED MECHANICS.

A. N. Talbot
In Charge of Thesis

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Head of Department

Recommendation concurred in:*

Committee on Final Examination*

*Required for doctor's degree but not for master's.

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Flow of Water through Submerged Orifices and Short Pipes with Mouthpieces.

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Flow of Water through Submerged Orifices and Short Pipes with Mouthpieces.

I. Introduction.

1. Preliminary.— Much experimental work has been done on the flow of water through orifices with discharge into air, although the results are not entirely consistent. For submerged discharge, however, experimental data are rather meager, particularly at low heads.

For flow through short pipes or tubes, whether with entrance inward projecting or flush, the experimental data for both free and submerged discharge are also scanty and conflicting.

Furthermore, the effect of attaching converging or entrance mouthpieces and diverging or discharge mouthpieces, of various lengths and angles, to a pipe has received very little attention, particularly with sizes and proportions commonly met in engineering practice.

The minimizing of entrance losses, the regaining of velocity head, as well as the producing of smooth flow in general is of considerable importance in many engineering problems. It is hoped that the investigation herein recorded may make available information which will be applicable to a variety of engineering needs.

2. Scope of Investigation.— The investigation was planned with the view of securing information on the following principal points:

A. Submerged Sharp-edged Orifices.

1. The effect of very low heads on the coefficient of discharge for orifices of various shapes and sizes.

2. The effect of shape (circular, square, and rectangular) on the coefficient of discharge.

3. The effect of size or area for any given shape on the coefficient of discharge.

4. The comparison of submerged discharge with free discharge.

B. Submerged Short Pipe with Mouthpieces.

1. The effect of very low heads on the coefficients of discharge and loss.

2. The effect of angle of convergence, for entrance mouthpieces, and angle of divergence, for discharge mouthpieces, on the coefficients of discharge and loss.

3. The effect of length of mouthpieces, both entrance and discharge, on the coefficients of discharge and loss.

While the experiments were in progress, some information was secured on the effect of depth of submergence and vortex motion of the water in the tank. Incidentally, a summary of the results of similar experiments by earlier experimenters is given which it is hoped may be found of value.

3. Acknowledgment.— The experiments were performed in the Hydraulic Laboratory of the University of Illinois. Much of the investigation was carried on as thesis work under the direction of Prof. A. N. Talbot by the following students:

Washington P. Ireland. Entrance Head in Pipes and Conduits, 1903.

Carroll C. Wiley. Entrance Head and Discharge Head in Pipes, 1904.

Ward R. Robinson. Entrance Head and Discharge Head in Pipes, 1906.

Guy D. Phillips. Discharge of Water through Submerged Orifices.

Ward R. Robinson, C. E. An Investigation of the Flow of Water

through Submerged Orifices and Pipes, 1909.

Charles William Bremner. Hydraulics of Culverts, 1912.

The care exercised in all of these theses is very commendable, and the patience and skill displayed in Mr. Robinson's second thesis has made the results at low heads of special value.

The data herein recorded represent the results of the above mentioned theses together with the results of a great many experiments carried out by the writer during 1914 and 1915 to determine the causes of certain inconsistencies as well as to check and extend certain parts of the investigation.

II. Apparatus Used and Method of Experimenting.

4. Orifices, Short Pipes, and Mouthpieces.— A list of the orifices, short pipes, and mouthpieces experimented upon is given in Table 1, while Fig. 1, 2, 3, 4, 5, 6, 7, and 8 show the apparatus used somewhat in detail.

Orifices.— The orifices used were of three different shapes; circular, 1 in. to 6 in. in diameter; square, 1/2 in. to 5-1/2 in. side; and rectangular, 1/2 in. x 6 in. to 2 in. x 6 in. In every case the orifice was formed in a cast iron plate, 10-1/2 in. diameter and 1/2 in. thick, a sharp edge being formed by beveling at 45 degrees. The workmanship was excellent, and except for a few small nicks, the edges were sharp and the area true to shape. The dimensions were carefully determined by an inside micrometer for dimensions greater than 1 in. and by inside screw calipers for dimensions less than 1 in. The actual areas of the orifices as calculated from these dimensions is given in Table 2.

Short Pipes and Tubes.— Four short pipes were used with

Table 1.

List of Orifices, Short Pipes, and Mouthpieces Used.

Orifices:-	Mouthpieces Used on 6-in. Short Pipe. Angle	Ratio of Area	
Circular:	5°	(1–2)	both entrance and discharge
1 in. diam.	10°	(1–2)	" " " "
~~1–1/2 in. diam.~~	15°	(1–2)	" " " "
2 in. diam.	20°	(1–2)	" " " "
4 in. diam.	30°	(1–2)	" " " "
6 in. diam.	45°	(1–2)	" " " "
	60°	(1–2)	" " " "
Square:			
1/2 in. side	10°	(1–3)	" " " "
1 in. side	15°	(1–3)	" " " "
2 in. side	20°	(1–3)	" " " "
4 in. side	30°	(1–3)	Discharge end only.
5–1/2 in. side.	45°	(1–3)	both entrance and discharge
	90°	(1–3)	" " " "
Rectangular:			
6 in. x 1/2 in.	20°	(1–4)	" " " "
6 in. x 1 in.			
6 in. x 2 in.			

Short Pipes: (cylindrical)	Combinations of Mouthpieces on 6–in. Short Pipes. Entrance End	Discharge End.
2 in. diam. x 5–1/2 in. long		
3 in. diam. x 12 in. long		
6 in. diam. x 22–1/2 in. long	15°(1–2)	15°(1–2)
12 in. diam. x 36 in. long	20°(1–2)	5°(1–2)
	30°(1–2)	5°(1–2)
	20°(1–2)	10°(1–2)
	20°(1–3)	15°(1–3)
	30°(1–2)	10°(1–2)
	30°(1–2)	30°(1–2)
	45°(1–2)	45°(1–2)
	60°(1–2)	60°(1–2)

Table 2.

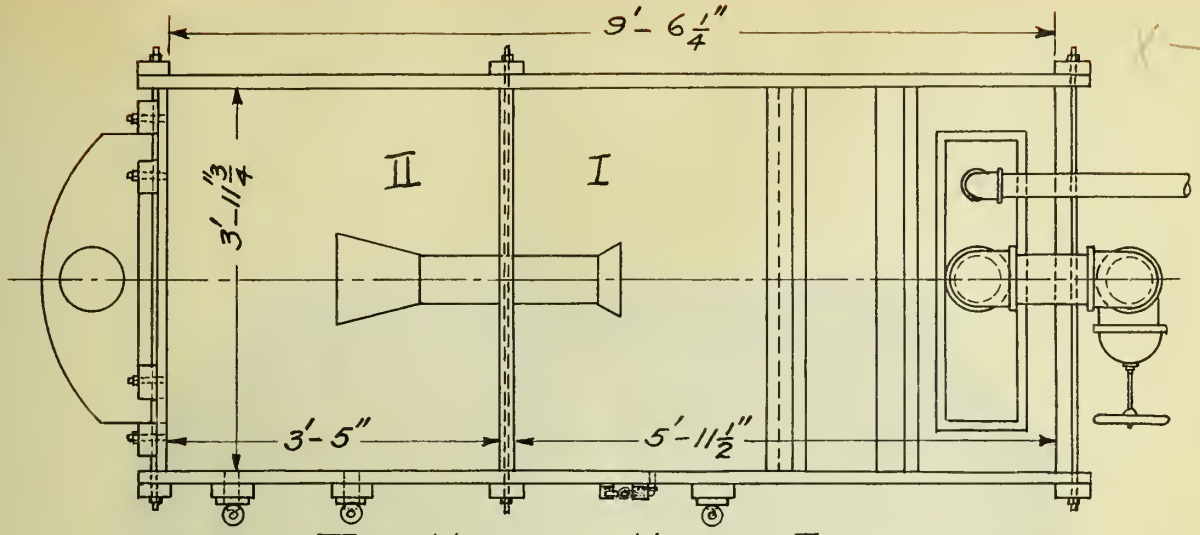
Areas of Orifices Used.

Kind of Orifice.	Nominal Size	Actual Area sq.ft.	Theoretical Rate of Discharge $a\sqrt{2gh}$ cu. ft. per sec.
Circular	1-in. diameter	Not measured.	
"	1-1/2 in. "	do.	
"	2-in. "	0.0219	$0.1760\sqrt{h}$
"	4-in. "	0.0883	$0.7075\sqrt{h}$
"	6-in. "	0.1967	$1.578\sqrt{h}$
Square	1/2 in. x 1/2 in.	0.001735	$0.0139\sqrt{h}$
"	1 in. x 1 in.	0.00698	$0.0558\sqrt{h}$
"	2 in. x 2 in.	0.0279	$0.224\sqrt{h}$
"	4 in. x 4 in.	0.1109	$0.890\sqrt{h}$
"	5-1/2 x 5-1/2 in.	0.2105	$1.688\sqrt{h}$
Rectangular	1/2 in. x 6 in.	0.0206	$0.1674\sqrt{h}$
"	1 in. x 6 in.	0.0418	$0.336\sqrt{h}$
"	2 in. x 6 in.	0.0837	$0.671\sqrt{h}$

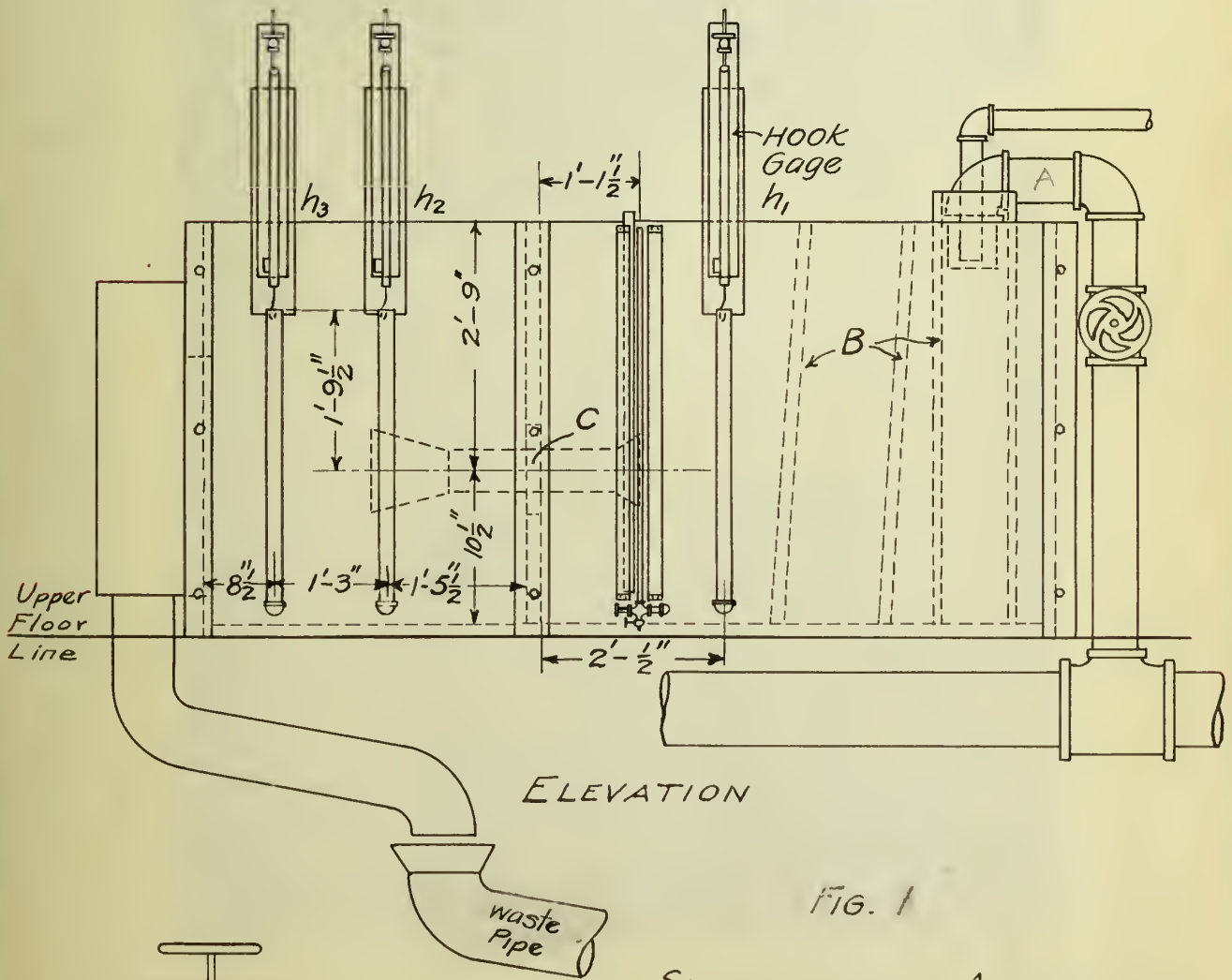
dimensions and conditions as follows: 2.085–in. diameter by 5–1/2 in. long with entrance flush; 3.107 in. diam. by 12 in. long with entrance inward projecting; 6 in. diam. by 22–1/2 in. long to which various conical mouthpieces both entrance and discharge were attached; 12 in. diameter by 36 in. long with vertical wing–wall entrance mouthpieces or approaches.

All except the 6–in. tube were sections of wrought iron or steel pipe, the 6–in. short pipe being cast iron bored carefully to a 6–in. diam. and threaded at each end to receive the various mouthpieces, Fig. 3. It had a flange near the middle by which it was attached to the partition separating the two compartments, with the pipe projecting into each compartment. The diameters of all the short pipes except the largest one (12 in. diam.) were carefully measured along the lengths of the tubes by means of inside micrometers, the average value given above being used in the calculation.

Mouthpieces.— Mouthpieces were used both on the 6–in. and 12–in. short pipes although they were very different in construction for the two pipes. With the 6–in. pipe conical cast iron mouthpieces were used, the dimensions of which are shown in Fig. 4 and 5. They were threaded in order to screw them on either end of the pipe. The smaller end of each mouthpiece was the same diameter as the pipe, making a smooth tight joint against the end of the pipe. The lengths of the mouthpieces varied, (depending upon the angle) so that the larger area of some was twice the area of the 6–in. pipe, denoted by (1–2), while others had an outer area of three times the area of the pipe, denoted by (1–3). One mouthpiece (20 degrees) had an outer area of four times the area of the pipe, denoted by (1–4). The mouthpieces or approaches used on the 12–in. diam. pipe consisted of wooden verti–



TOP VIEW OF UPPER FLOOR.



ELEVATION

FIG. 1

SKETCH SHOWING ARRANGEMENT OF APPARATUS FOR SUBMERGED SHORT PIPE WITH MOUTHPIECES.

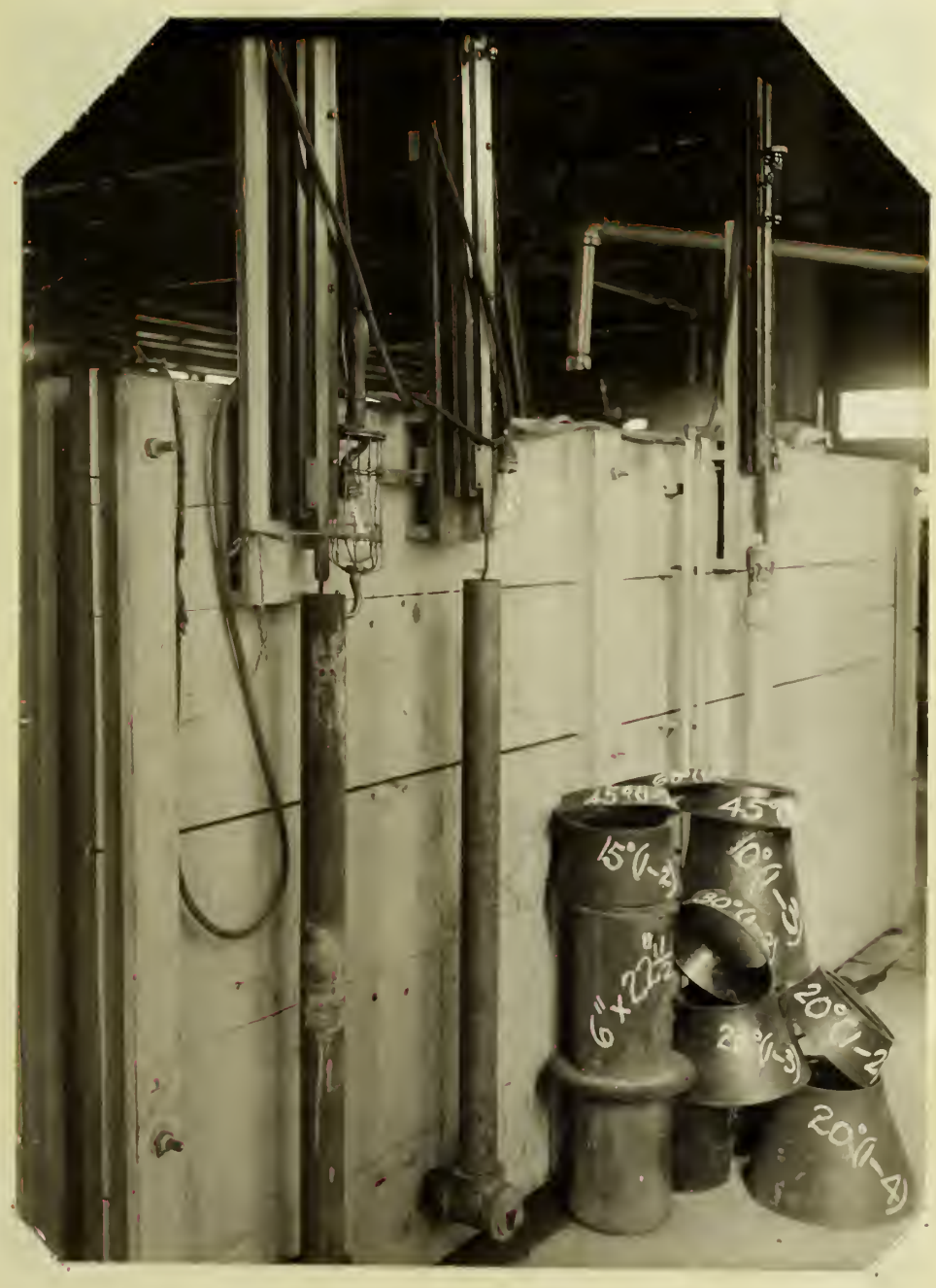


Fig. 2.

Tank Used for Orifices and Short Pipe with Mouthpieces.

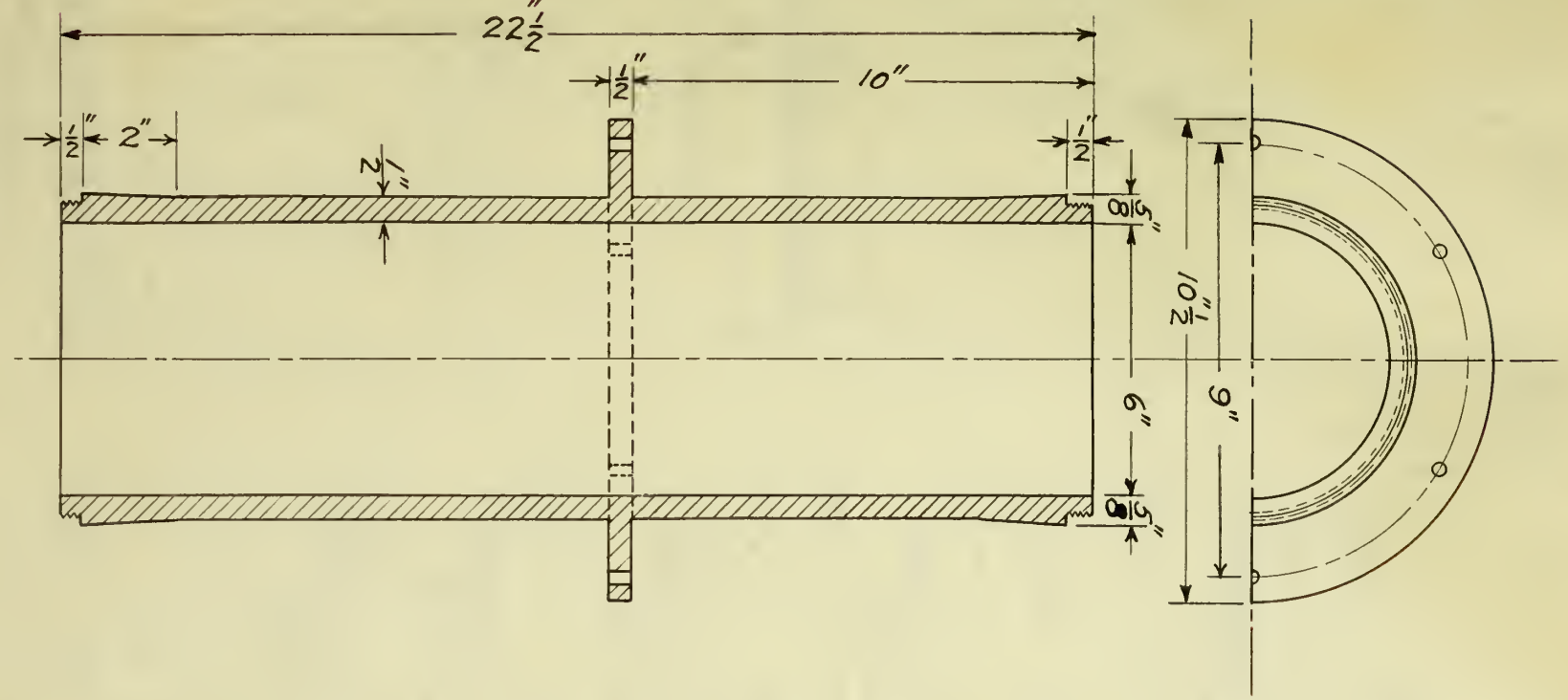


FIG. 3. 6-IN. × 22½-IN. SHORT PIPE
ON WHICH
MOUTH PIECES WERE SCREWED

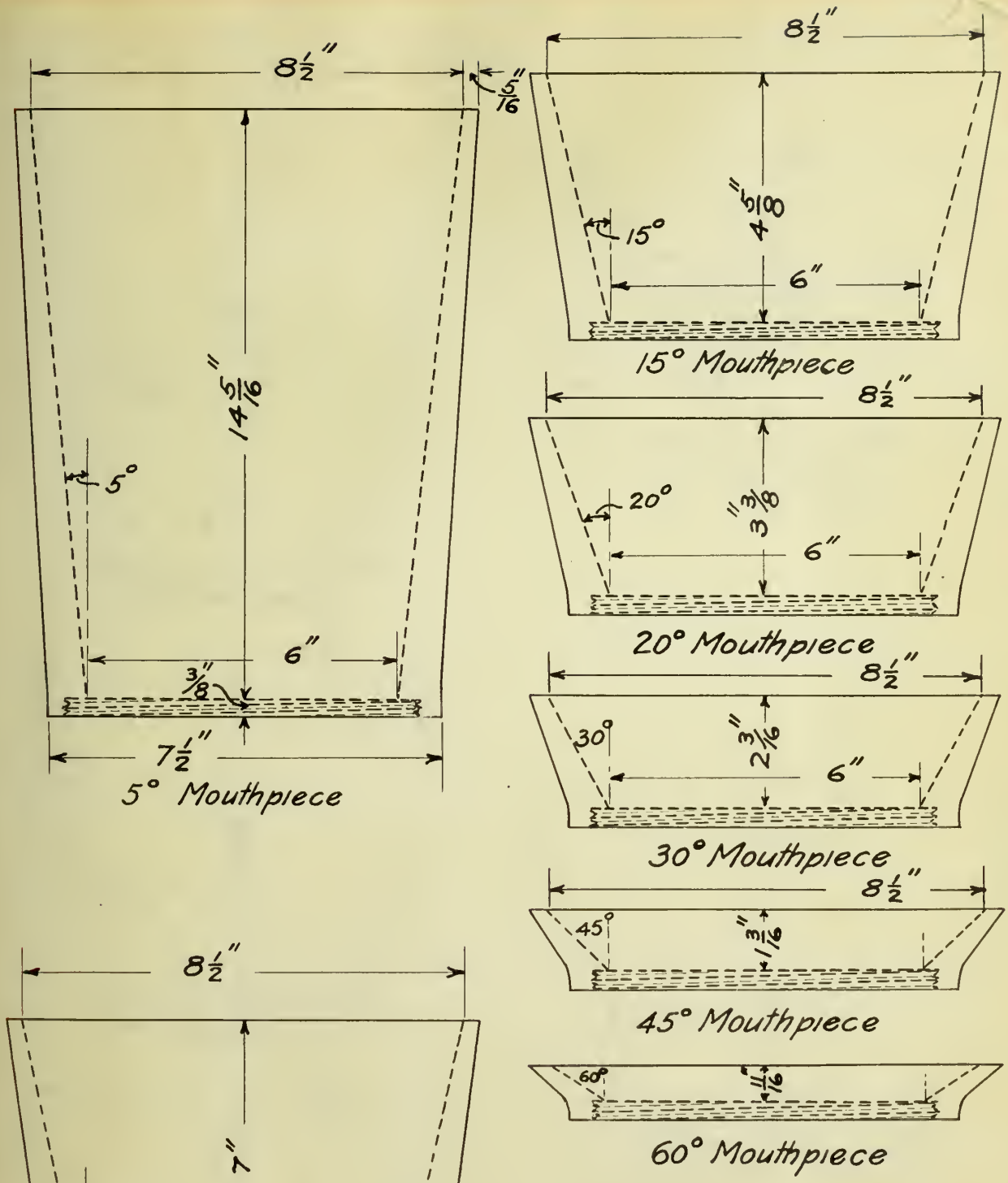
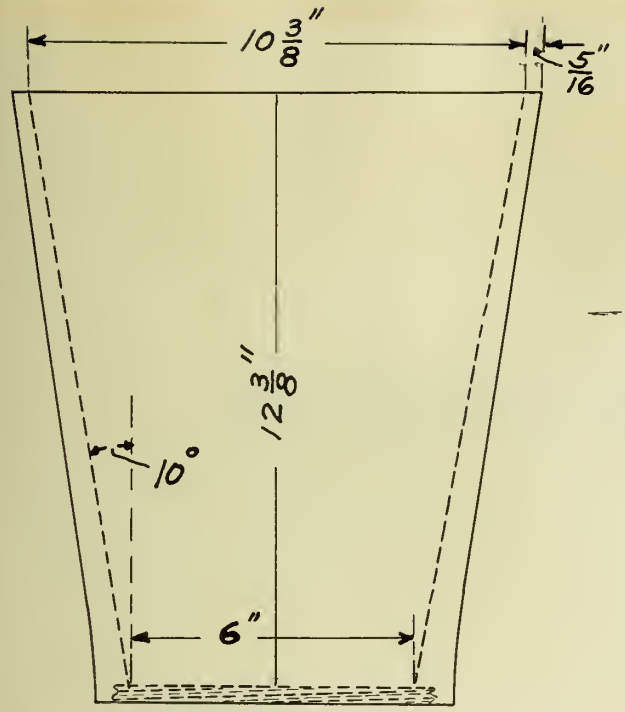
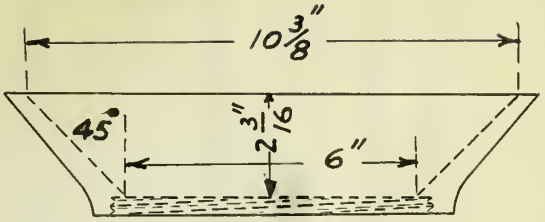


FIG. 4.

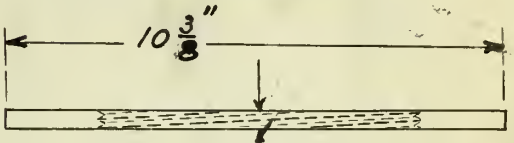
(1-2) Mouthpieces used on 6-in. Short Pipe



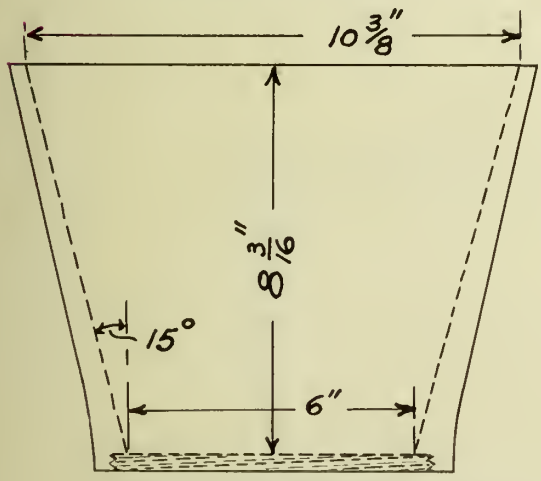
10° Mouthpiece



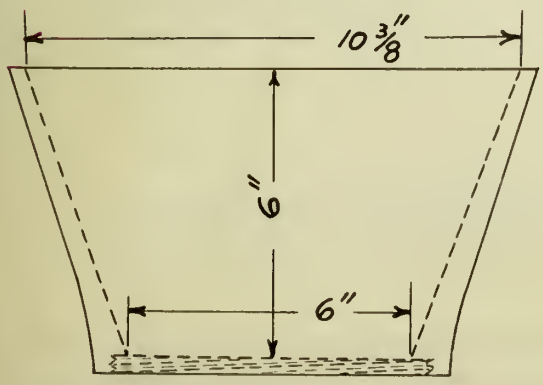
45° Mouthpiece



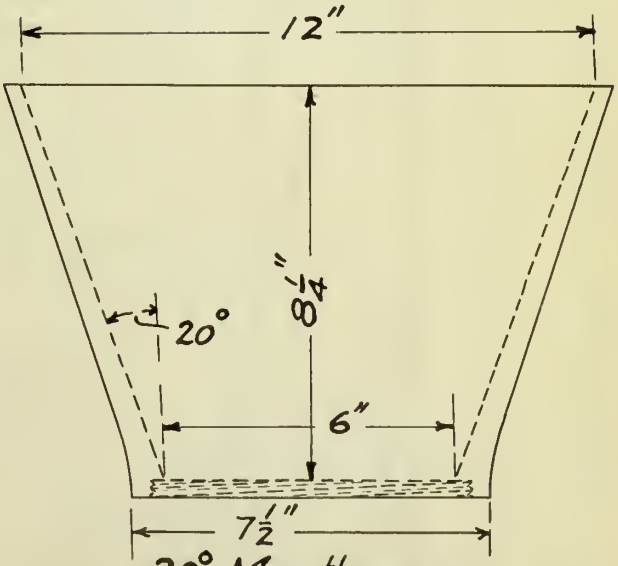
90° Mouthpiece



15° Mouthpiece



20° Mouthpiece



20° Mouthpiece
(1-4)

Fig. 5

(1-3) Mouthpieces used on 6-in. Short Pipe

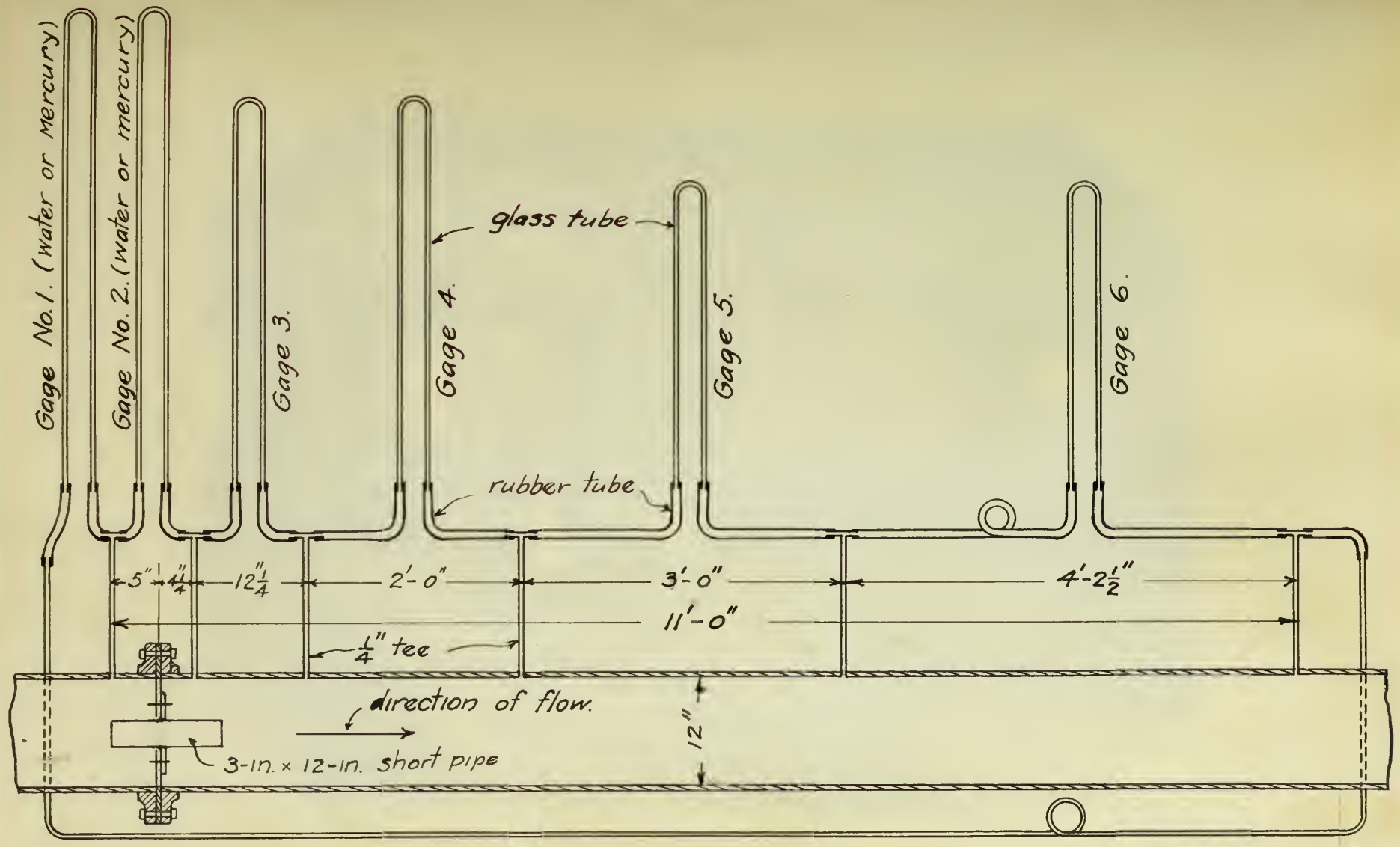


FIG. 6. APPARATUS USED WITH 3-IN. SHORT PIPE INSIDE 12-IN. PIPE.

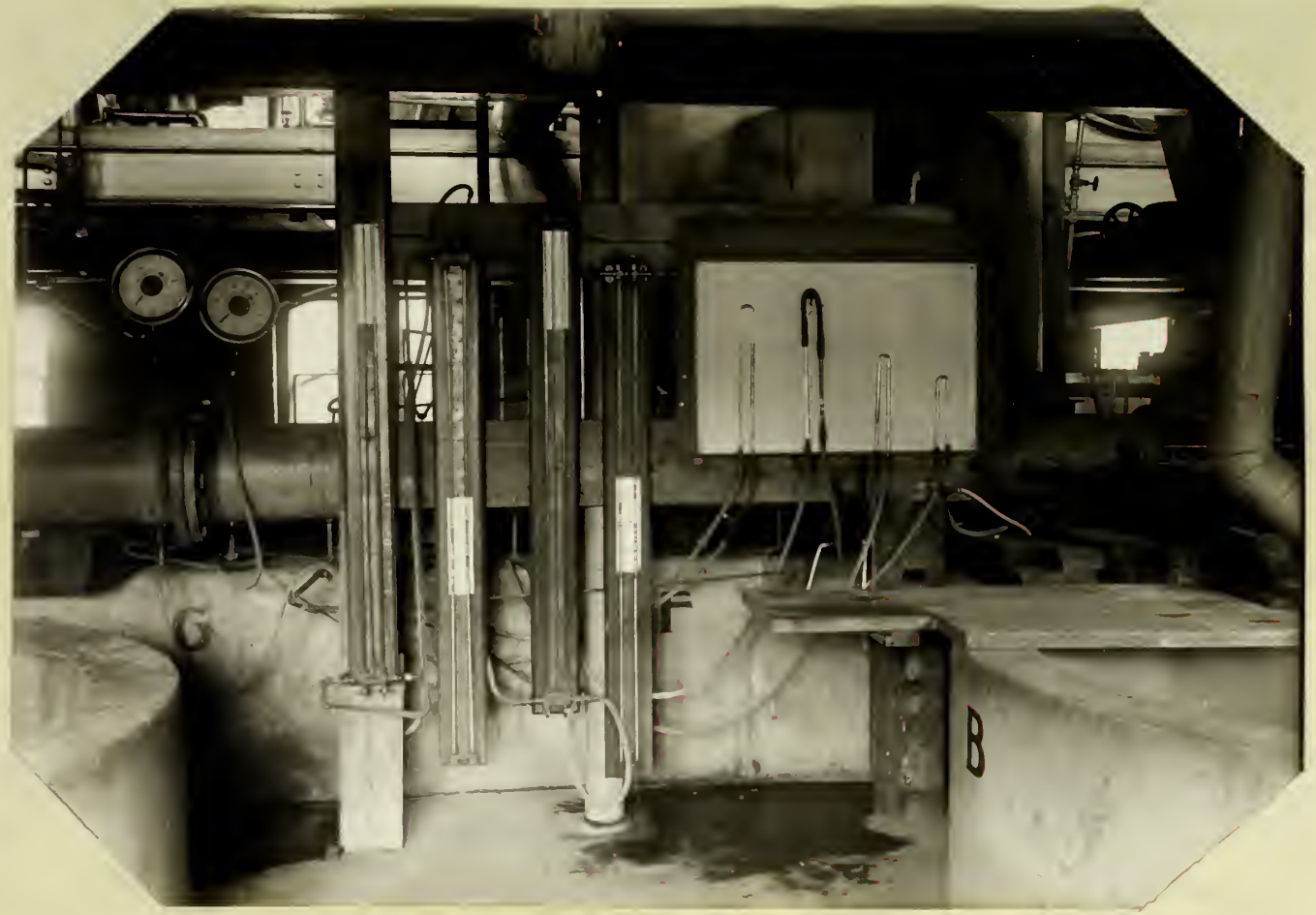


Fig. 7.
Apparatus Used for 3-in. Short Pipe Inside 12-in. Pipe.

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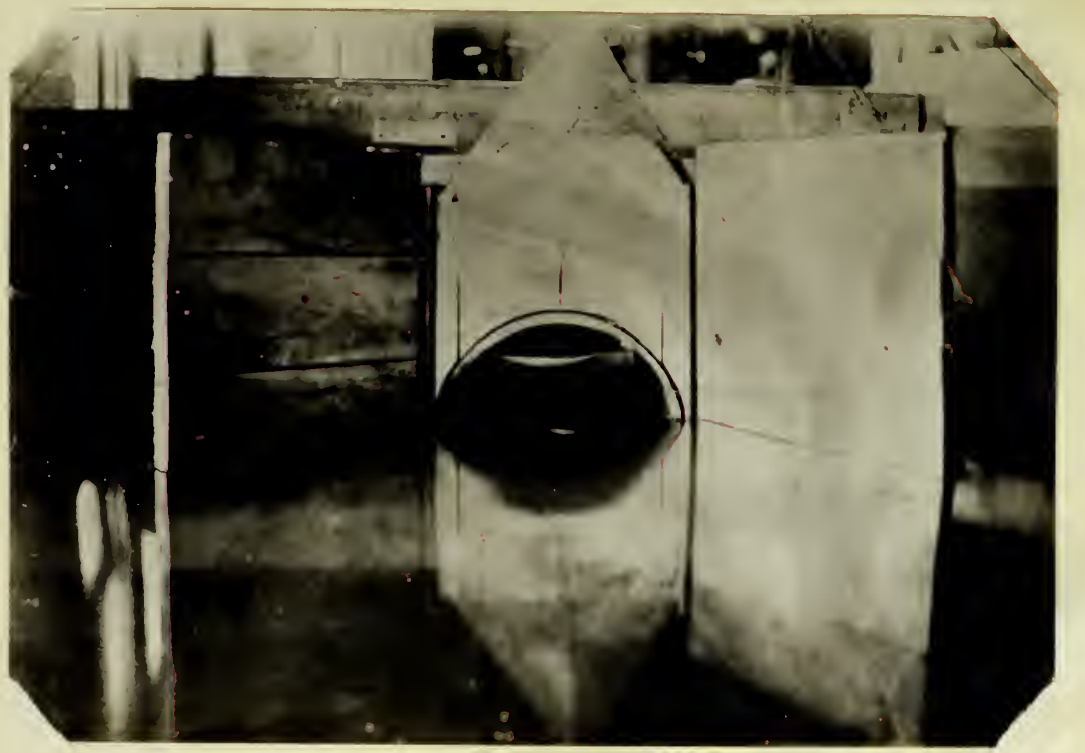

Fig. 8.

12—in. Short Pipe with Wing—walls.

cal wing-walls built of dressed and matched flooring and so constructed that the wings could be swung on hinges to any desired angle of approach with the axis of the pipe as shown in Fig. 8. For a 90° angle (flush entrance) a straight-wall was used instead of wing-walls. This straight-wall was square of such a size that its four edges were 2 diameters from the circumference of the pipe.

5. Method of Experimenting.— The tank used in all of the experiments on the orifices, the 2-in. pipe and the 6-in. pipe with its mouthpieces, as well as for some of the experiments on the 3-in. pipe, is shown in Fig. 1 and 2. The tank is divided into two compartments, I and II, Fig. 1, which are separated by a partition containing an opening at C, into which may be fitted the orifice or tube to be used. The water coming from the standpipe is supplied to the tank through a 6-in. supply pipe at A, and also through a 2-in. pipe which made possible a finer adjustment in maintaining a constant head. The water, after passing through the baffle boards at B and through the orifice or short pipe at C, finally leaves compartment II through two long, narrow, vertical openings in the end of the tank, the flow through which is regulated by small valves or stoppers. For small discharges, the water was either weighed in a tank set on scales or measured in a pit 8 ft. in diam. and 6 ft. deep, the rise being determined by means of a hook gage. The water was wasted into another pit through a movable spout until the surface in the measuring pit became still. After the run had been made, the water was again wasted and the rise could be determined. For larger discharges the rise in the pit was determined by means of a rod on the lower end of which was attached a ring of thin metal, a small part of the circumference of the ring being slight-

ly lower than the remaining portion. The instant the lower portion touched the water surface the fact was at once noticeable and the reading was taken. For some of the later experiments, the rod was replaced by one containing a float on the lower end.

In a few cases the discharge through the 6-in. pipe was measured over a 3-ft. suppressed weir, the coefficient for which was taken from Hamilton Smith's tables. The head on the weir was measured in a still basin by means of a hook gage.

The 12-in. pipe was placed in a horizontal position in a large weir channel with one end protruding through a hole in a water-tight bulkhead built across the channel and the other end supporting one of the above described wall entrances resting on an A-frame or support as shown in Fig. 8. After discharging through the pipe, the water was measured over a 3-ft. weir, the head on which was measured in a still basin by means of a hook gage.

In order to obtain data which might help determine the effect of form and size of the tank used, depth of submergence, etc., as well as to obtain higher heads, the 3-in. pipe, after being tested in the tank described above, had its flange bolted to a thin steel plate which was cut out in the middle to a 4-in. diameter allowing the 3-in. pipe to project through. This steel plate in turn was placed between the flanges of two sections of 12-in. pipe holding the 3-in. pipe in the center of the 12-in. pipe, and allowing no water to pass except through the 3-in. tube (Fig. 6 and 7). The discharge was weighed for small quantities of flow and measured in a large calibrated galvanized tank 6 ft. diam. and 12 ft. deep for large discharges.

6. Methods of Measuring Heads.-- The method employed for measuring the very low heads was different from that used in determining

the moderately low heads. Except in the case of the 3-in. pipe as used inside of a 12-in. pipe, all heads were under 2 ft. and the greater portion were under 0.5 ft., the minimum values being 0.002 to 0.004 ft. For values greater than 0.05 ft. the head, which is the difference of level of the water surface in the two compartments of the tank, was determined by means of two 1/2-in. glass piezometer tubes, one attached to each compartment about three inches from the bottom of the tank. A vertical scale reading to 0.01 ft. placed close to the glass tube enabled the observer to read to 0.001 ft. by estimating. In the latter experiments, boxes were placed around the opening at the entrance of the piezometer tube into the tank to form a still basin. It was thought that at the higher heads the currents of water might affect the head somewhat, due to the shortness of the tank. The results, however, show no effect from this cause. The zero-reading of the piezometer tube was determined by filling the tank to a given level and allowing no water to flow in or out. The readings of the piezometer glasses could then be made, the difference giving the zero-reading. The tank was filled to several different levels in making the readings and an average value of the zero-reading used in the calculations. Leakage from the tank, as well as from the measuring pit, was determined by filling to a given level and observing the gages at intervals of time. The leakage was negligible in all of the experiments.

For measuring very low heads two methods were used consisting (1) of a differential gage employing a liquid heavier than water, (2) hook gages.

(1) In the place of the glass piezometer tubes described above, a differential gage was used. This was connected to the tank by

means of rubber tubing and was provided with a scale graduated to 0.005 ft. A mixture of carbon tetrachloride and gasoline having a specific gravity of 1.25 was used in the gage, thus multiplying the actual head by four.

(2) At another opening in each compartment of the tank a vertical 2-in. pipe was attached which served as a still basin for a hook gage as shown in Fig. 1 and 2. Each gage was read directly to 0.001 ft. and to 0.0001 by estimating. The zero-reading was obtained as in the case of the piezometer tubes, described above. In the latter experiments another pipe and hook gage was attached to the down stream compartment, using the same piezometer opening as was used in the case of the glass tube.

This furnished two readings of the height of the water surface in the down stream compartment in which the water became rather turbulent as the discharging head increased.

These different methods of determining the head overlapped so that certain heads were determined by all three methods, and many values were determined by at least two methods. This, it is thought furnishes an excellent check on the coefficients obtained.

In reading the hook gages at low heads, electric lights held always in the same position made it possible to get accurate settings of the hooks.

The stoppers in the long vertical openings in the end of the tank were controlled so as to give a uniform distribution of flow vertically and also to give about equal discharges through the two openings. This, it was found, helped to produce more steady conditions of flow.

The diameter of the measuring pit was taken as 7.995 ft., the

mean of thirty readings. The largest variation from the mean was 0.003 ft.

A run or experiment consisted, first, in adjusting the inflow through the 6-in. and 2-in. pipes to the outflow, when a few of the stoppers were removed, until the difference in level of the water in the two compartments became constant. The 2-in. pipe was used merely as a means of making the adjustment more quickly, and of maintaining the water surface constant during the run, if for any reason, they tended to rise or fall slightly. After obtaining a constant head the spout of the waste pipe was quickly pulled from beneath the end of the discharge pipe, allowing the water to discharge in the measuring pit until the rise in the pit was sufficient to read the pit gage without appreciable error, when the waste pipe was again pushed quickly under the discharge pipe.

The time of the run was determined by means of a stop watch. After breaking one watch, another one was used before being calibrated, and after quite a number of experiments the calibration showed the watch to be very erratic. Some of the erratic results obtained, it is thought, are due to this cause.

The experiments were run for the most part when the laboratory was used for no other purpose. Under some of the extremely low heads attempted, vibrations of the buildings due to running machinery caused difficulty in reading the hook gages. The pressure also was much more constant when water was supplied for no other use.

7. Notation.-- For convenience of reference, the following notation which will be used in the subsequent equations is given here.

h = head producing flow, "flow head" in feet. For submerged discharge this is the difference in level of the water on the

two sides of the partition.

h' = head lost by shock or impact due to contraction and expansion of the stream, feet.

a = area of orifice or short pipe, sq. ft.

A = area of outer or larger end of mouthpiece, sq. ft.

g = acceleration due to gravity = 32.2 ft. per sec.

q = actual discharge, cu. ft. per sec.

Q = theoretical discharge, cu. ft. per sec.

v = actual average velocity, ft. per sec.

c = coefficient of discharge.

c' = coefficient of contraction.

c_v = coefficient of velocity.

c_p = value of c for a short tube having no mouthpieces (inward projecting).

c_r = increase in c_p due to an entrance mouthpiece.

c_n = increase in c_p due to a discharge mouthpiece.

c_c = calculated value of c for a combination of an entrance mouthpiece and a discharge mouthpiece on the 6-in. pipe.

$$c_c = c_p + c_r + c_n.$$

m = coefficient of loss = $\left(\frac{1}{c_v^2} - 1\right)$ or $\left(\frac{1}{c^2} - 1\right)$ if $c_v = c$.

m_p = value of m for a short pipe without mouthpieces (inward projecting)

m_r = reduction of m_p due to an entrance mouthpiece.

n = reduction of m_p due to a discharge mouthpiece, sometimes called coefficient of gain.

m_c = calculated value of m for a combination of an entrance and a discharge mouthpiece on the 6-in. pipe. = $m_p - m_r - n$.

8. Theory and Equations.-- Orifices.-- The head, h, causing flow through an orifice is expended in two ways: (a) lost head, h', representing energy dissipated by impact and friction of the water particles due to the contraction at entrance and expansion after the water leaves the orifice, and (b) head which produces the velocity of the stream or $\frac{v^2}{2g}$, the velocity head. Hence

$$h = h' + \frac{v^2}{2g} \quad \text{or} \quad h' = h - \frac{v^2}{2g}$$

but, $v = c_v \sqrt{2gh}$ or $h = \frac{v^2}{c_v^2(2g)}$.

Substituting in the above equation gives an expression for the lost head in terms of the velocity head,

$h' = \left(\frac{1}{c_v^2} - 1\right) \frac{v^2}{2g}$, in which $\left(\frac{1}{c_v^2} - 1\right)$ is denoted by m and called the coefficient of loss. The first equation, then, may be written $h = (m+1)\frac{v^2}{2g}$.

For submerged discharge, the coefficient of velocity cannot be determined as the contraction of the stream is unknown. For purposes of comparison the coefficient of discharge will be used in the expression for m.

Short Pipes.-- A short pipe or tube is defined as one whose length is not more than three or four times its diameter or side, but long enough to have the stream expand again after contraction at entrance and flow full at the discharge end. The short pipes used in these experiments varied in length from 2.75 to four times the diameter, the 6-in. pipe on which the greatest number of experiments were run having a ratio of length to diameter of 3.75.

Since there is no contraction of the discharging stream, the coefficient of velocity and the coef icient of discharge are the same.

The lost head due to the frictional resistance along the sides of the tubes, usually expressed by $\frac{fl}{d}\frac{v^2}{2g}$, is small and will be included in the lost head, h'.

The equation therefore remains as in the case of an orifice $h = \left(m_p + 1\right)\frac{v^2}{2g}$ where m_p will include the effect of pipe friction.

If a converging entrance mouthpiece is attached to the short pipe, the contraction of the stream at entrance will be somewhat suppressed, reducing the lost head and hence also the value of m, This reduction in the coefficient of loss will be denoted by m_r.

If a diverging mouthpiece is attached to the discharge end of the short pipe, a part of the velocity head may be regained. The theoretical amount possible of recovery may be calculated if the ratio of the area of the pipe to the area of the outer end of the mouthpiece, $\frac{a}{A}$, is known. The velocity at exit from the mouthpiece would then be $\frac{a}{A}$ v, where v is the mean velocity throughout the pipe to which the mouthpiece is attached. The reduction in the velocity head is, therefore, $\left[1 - \left(\frac{a}{A_1}\right)^2\right]$. In other words, if the velocity could be reduced without shock or eddying, a discharge mouthpiece having the ratio of its area as one is to two, (1 ∠ 2), would regain 75% of the velocity head coming from the straight pipe while a (1–3) discharge mouthpiece would regain 88% of the velocity head, and a (1–4) divergent mouthpiece would regain 94% of the velocity head.

The amount of velocity head recovered, then, may be written $n\frac{v^2}{2g}$ which may be considered as a negative loss.

The value of m_p for the plain pipe inward projecting into each compartment of the tank is determined by experiment. The value of

m for a combination of any entrance mouthpiece with the short pipe is also determined experimentally. The difference in these two values gives the reduction, m_r, in m_p, caused by the mouthpiece. Likewise, the value of m for any discharge mouthpiece combined with the short pipe is determined by experiment, after which the value of n is found from the equation $n = m_p - m$. If both an entrance and a discharge mouthpiece is attached to the short pipe, the value of m obtained experimentally may be compared with the value of m as calculated from the data obtained with the separate mouthpieces. Denoting the calculated value by m_c, its value will be $m_c = m_p - m_r - n$. This is discussed later. The temperature of the water varied from 60 to 70 degrees Fahr. No account is taken, therefore, of the temperature effects for so small a variation. From Unwin's experiments an increase in temperature of 144° caused 1% decrease in the discharge.

III. Experimental Data and Discussion.

9. Tables and Figures.-- The data obtained by all the experimenters are given in somewhat condensed form in Table 5 to 8 , inclusive. Each set of values represents the averages of two to ten experiments or runs.

The data obtained by the writer in checking and extending the work of the other experimenters are given in Table 17 to 20, inclusive. Table 14 to 16 show the results of the experiments with the 3-in. x 12-in. short pipe placed inside a 12-in. pipe. Figs. 16 to 28 inclusive show the results of Tables 6 to 8 , plotted to show the relation between the head and the coefficient of discharge. The final values for the coefficients of discharge with the corresponding values of the coefficients of loss were taken from these graphs.

Tables 9 to 13 with Figs. 9 to 14 show the final values of the coefficients of discharge and loss.

10. Discussion of Results.-- Certain inconsistencies seemed to exist in the results of the other experimenters which necessitated further investigation. The coefficient of discharge, c, for the 6-in. pipe with flush entrance - 90°(1 - 3) entrance mouthpiece -- was found by Robinson to be about 0.91 and for the 2-in. tube c was found to be about 0.88, whereas the usual text book value is 0.82, taken from experiments chiefly with discharge into air. It was found, however, that an error in the diameter of the 2-in. pipe reduced the value of c to about 0.81, while considerable additional experimenting fixed the value for the 6-in. short pipe at slightly greater than 0.800.

The value of c for entrance inward projecting varied with the various experimenters from 0.78 to 0.800, whereas the commonly ac-

cepted value, taken from meager tests in which the discharge was in air, is c = 0.72. A 60° mouthpiece on the discharge end gave a value for the coefficient of discharge of about 0.78. While it would be expected that a 60° mouthpiece would regain very little velocity head, there seemed little reason to expect a negative effect from it. Further careful experiments fixed the value of c for inward projecting entrance at c = 0.785, which indicates that a 60° mouthpiece has little or no effect.

The values obtained at low heads using the differential gage containing a mixture of tetrachloride and gasoline gave consistently lower values for the coefficient of discharge than were obtained when the hook gages were used.

The differential gage was connected to the down stream compartment 15-in. nearer the partition separating the two compartments than was the 2-in pipe which served as the still basin for the hook gage. In order to determine any effect which might result from this cause, another hook gage was attached to read the water surface at the same point of connection used with the differential gage. The results clearly indicate that the differential gage gave too small values at low heads.

As will be noted in Table 17 to 20 the difference between the readings of the hook gages, $(h_3 - h_2)$ and $(h_3 - h_1)$, Fig. 1 and 2, in many cases show a considerable variation. In some experiments it was found very difficult to maintain the water surfaces constant. This changing of the water surfaces while probably affecting the actual difference in the heights of the surface levels very little made necessary the accurate setting of three hook gages as nearly simultaneously as possible for each set of readings. The greatest errors which were introduced into the experiments, it is thought, were

from this cause. However, even when the water surface remained practically constant for the whole run, a slight difference in the values of $(h_3 - h_2)$ and $(h_3 - h_1)$ was sometimes shown. It should be remembered, however, that the discharge varies as the square root of h, which considerably reduces the percentage error introduced by the hook gage readings. The water surface levels, too, fluctuated, as a rule, less with the low heads, Hence, for heads with which errors would have a large effect, less difficulty was experienced in obtaining simultaneous readings of the hook gages.

It is to be expected that the values of the coefficients of discharge and loss will appear rather erratic at low heads. In some cases, the value of the coefficient of discharge increases as the head decreases, in others it decreases, while in still others it remains constant to heads as low as 0.004 ft. This strongly indicates that for submerged discharge, the coefficient of discharge is constant for all heads below 0.8 ft. and velocities below 6 ft. per sec., no matter how small. There seems to be, however, a marked tendency in some cases for the coefficient of discharge to increase with the higher heads. This is discussed in the next two articles.

11. Vortex Motion.— During the experimenting, it was noticed that the higher heads fluctuated at times for apparently no good cause. It was noticed, however, that vortex motion of the water in the up-stream compartment was more active on these occasions of unsteady conditions.

The vortex motion was always counter clockwise, due, no doubt, to the fact that the 2-in. supply pipe discharge was near one side of the box.

The vortex formed a tapering hole about 1-1/2 in.diameter (max-

imum) at the water surface, extending to a point ten inches or a foot below the surface. In no case did it appear to allow air to enter the tube. On some runs, this condition formed and remained rather constant for all or a considerable part of the run, while in others it formed, disappeared, and formed again, successively.

In order to study the effect of the vortex motion, a float of 2-in. planks was made which fit loosely in the upper compartment. This floated in the water surface and suppressed the vortex.

The experimental results (see Table 7) clearly indicate that the vortex motion may increase the discharge by at least 2%. In some cases where the float did not produce a difference in discharge it did maintain less fluctuation and thereby reduce the error in measuring the head. If the vortex had completely formed so that air had entered the tube, without doubt, the discharge would have been decreased. It would appear, however, that the swirling motion of the water allowed it to enter the tube or mouthpiece with less contraction and, hence, produced a greater discharge.

This perhaps accounts for at least a part of the increase in some of the coefficients of discharge at the higher heads.

12. Depth of Submergence.-- While no experiments were run which would determine accurately the effect of depth of submergence upon an orifice or short pipe, the conditions were such as to supply considerable indirect evidence bearing on this point. The water surface in the upper compartment was kept nearly constant for all heads, the head being increased by lowering the surface level in the down stream compartment. This caused a maximum change in the depth of submergence about equal to the maximum head. This, in the case of the smaller orifices, amounted to 1.5 ft., and in the case of the 6-in. short pipe frequently reached 0.75 ft. The greatest depth

of submergence possible with the tank used was about 1-1/2 ft. The coefficient of discharge shows a tendency to increase as the head increases, that is, as the submergence decreases. It seems, however, that the shortness of the tank with the higher velocities, and the attendant turbulence would be as an important factor as the submergence.

Furthermore, in the case of the 3-in. tube placed inside the 12-in. long pipe, the discharge end of the tube was under a wide range of pressures which corresponds to the depths of submergence in the tank, and under different pressures also for the same head. No change in the coefficients could be detected, however, due to this cause. In fact, the coefficient of discharge for the 4-in. short pipe showed a greater increase with an increase in head when tested in the tank than when tested in the long pipe. It would seem, therefore, that depth of submergence had little influence in these experiments, or at least, the form and size of the tank, together with vortex motion had more influence than depth of submergence.

13. Coefficients of Discharge and Loss for Submerged Orifices.--The coefficients of discharge and loss vary considerably for the submerged orifices. This is to be expected, however, as already discussed. There is no evidence, though, of a decrease or increase in c or m as the head becomes very small. The experimental data in Table 3 seems to justify the statement that the coefficients of discharge and loss are constant for all heads from 0.005 to 1.00 ft. corresponding to velocities of about 0.40 to 5.00 ft. per sec.

Table 9 and Fig. 9 and 10 show that the coefficients of discharge for circular and square orifices are practically the same for areas greater than ten square inches, but that as the area

decreases below ten , the value of c increases faster for circular than for square orifices. It is clear also that rectangular orifices give higher coefficients of discharge than do the circular or square ones. The sizes of rectangular orifices used showed no increase in c for the smaller areas. It is possible that the diverging sides of the orifices had some effect in increasing the discharge with the smaller sizes and that this influence was active in all of the rectangular orifices due to their long narrow shape. There seems to be little evidence in these experiments to point to a difference in free and submerged discharge for sharp-edged orifices, allowing complete contraction.

In this connection, it is of interest to consider the conclusions reached by H. J. I. Bilton from his experiments on orifices discharging in air:-

1. The assumption that a coefficient of discharge common to all orifices from 1/2 in. to 12 in. diameter is reached at a head of 100 ft. is erroneous.

2. That in order to obtain complete and perfect contraction a certain minimum diameter and head are required. These appear to be approximately 2-1/2 in. and 17 in. respectively.

3. That orifices of 2-1/2 in. diameter and over under heads of 17 in. and over have a common coefficient of discharge lying between 0.59 and 0.60, but which is probably about 0.598 (subject to head being not less than 2 or 3 diameters,

4. That in the case of orifices smaller than 2-1/2 in. diameter contraction is never perfect and complete under any head, but is suppressed more and more as the diameter increases, each size of orifice having its own critical or "normal" coeffi-

cient of discharge and its own critical head.

5. That as the diameter decreases, the normal coefficient increases, as also the critical head.

6. That in an infinitely small orifice contraction is entirely suppressed and unity becomes the coefficient of discharge for all heads (subject to the effects of capillarity, cohesion, viscosity, temperature, etc.)

7. That the discharge of a circular orifice under any given head is the same, whether the jet be horizontal, vertical or at any intermediate angle.

14. Coefficients of Discharge and Loss for Short Pipes with Inward Projecting Entrance.-- The values of c = 0.71 or 0.72 for the coefficient of discharge for a short pipe inward projecting in the up stream reservoir with the corresponding value of m = 0.98 to 0.93 for the coefficient of loss, which are so commonly stated, seem to have been based on rather meager data as shown under "Results of Earlier Experimenters".

The values obtained by Bilton with free discharge seem to bear out some of the conclusions given by him in connection with orifices as stated above.

The values for c and m obtained from the present experiments with the 6-in. submerged short pipe are c = 0.785 and m = 0.610 for heads under 0.8 ft. and velocities under 6 ft. per sec. Furthermore, the experiments on the 3-in. short pipe placed inside the 12-in. long pipe show no change in c as the head increases up to a maximum of about 12 ft. It would be expected that this method of testing would give somewhat different values for c from those obtained with the tube placed in the open tank, but the variation with

the head should not be greatly different.

It is possible that the head as measured by the hook gages at the side of the tank does not represent the head on the discharge end of the tube; that if the pressure could be obtained nearer to the end of the short pipe, the results would show a larger flow head and, hence, a smaller coefficient of discharge. This is suggested by the results of the experiments with the 3-in. tube placed inside the 12-in, pipe. Considering the flow head as the difference in heads on the two sides of the flange (gage No. 2, Tables 14, 15, and 16) the coefficient of discharge is closely the same as obtained for the same tube when discharging into air, with the discharge end flowing full, but somewhat smaller than for submerged discharge as determined in the open tank.

Considering the flow head as gage reading No. 1, that is, after some of the velocity head is regained, c is larger than that obtained with the open tank. It is of interest to note that the average of c as determined from these two different heads, corresponds very closely with the value of c obtained for submerged discharge in the open tank.

The low values of the coefficient of discharge for the 12-in. and 3-in. short pipes under low heads for discharge into air, indicates that quite different conditions exist in the tube for a low value of the ratio of head to diameter, h/d, than exist for high values of this ratio. In the case of the 12-in. tube the ratio of h to d was unity. Taking into consideration the variation in head over the entrance area will decrease the theoretical discharge about 1%, that is, increase the coefficient of discharge by about 1%. The greatest difference in the conditions of flow under high and low

heads, however, is not in the variation of head on the entrance area but in the contraction and subsequent expansion within the short pipe. It is not sufficient to state that the discharge end must flow full in order to insure standard conditions of flow. The 3-in. short pipe under a head of 0.76 ft. flowed full, but gave c = 0.730 as compared with c = 0.775 for a head of nearly 2 ft. Under the head of 0.76 ft. the variation of velocity across the discharge area was very great, being almost zero at the top while under the 2-ft. head, the water seemed to issue in nearly parallel stream lines of equal velocity. It is clear that the contraction and expansion must be very different in the two cases. Even for a submerged discharge, Stewart found with a 4-ft. square tube, that the discharge end did not flow full with the lower heads, there being a current up stream in the upper part of the discharge area.

The condition of flow within the tube for low heads even though the discharge end flows full, may be judged from the conditions which exist when the discharge end is not flowing full. The profile of the water surface in an open culvert 6-in. wide by 3 ft. deep is shown in Fig. 15. Experiments on the 12-in. tube showed similar action. It is clear that the weight of the water plays an important part in the contraction and expansion. Under low heads, excessive energy is lost both by dissipation and by failure of recovery from the velocity head by proper expansion.

15. Coefficients of Discharge and Loss for Short Pipes with Flush Entrance.-- Earlier experiments on short pipes with flush entrance are more abundant than in the case of inward projecting entrance. The conditions under which some of the experiments were run, however, are somewhat indefinite. The value for c for flush entrance is

usually given as 0.815 or 0.820. The value of m corresponding to c = 0.820 is 0.49, commonly taken as 0.50. The values of c and m for the submerged 6-in. short pipe in these experiments is c = 0.800 and m = 0.56. For further discussion, see "Results of Earlier Experimenters".

16. Effects of Entrance and Discharge Mouthpieces.-- The values of the coefficients of discharge and loss for the various mouthpieces are given in Tables 6 to 11 and Fig. 11 to 14. While there is a slight tendency for the coefficient of discharge to increase for the higher heads in the case of some of the mouthpieces, when considered in connection with vortex motion, form, and size of tank, etc., as already discussed, together with the results from the experiments as a whole, it seems there is little doubt that the coefficient of discharge is constant for all heads below 0.8 ft. and velocities below 6 ft. per sec.

The discharge is due partly to the negative pressure in the tube which increases as the velocity (and head) increases. The fact that c is constant would indicate that the negative pressure increases at the same rate as the head. These results make plain several rather definite conclusions. An entrance mouthpiece with ratios of areas of one to two, one to three, and one to four, give practically the same discharge, that is, the angle of approach has greater influence than the length of the mouthpiece, although within the range of 10° to 45° (20° to 90° apex angle) the coefficients of discharge are not greatly different. It is probable that if the mouthpieces had flush entrances, the discharge would be increased slightly. It is possible that in the case of the 5°(1 - 2) entrance mouthpiece, velocity of approach was not negligible due to the nearness of the outer end of

the mouthpiece to the bafile boards.

Discharge mouthpieces of the same angle of divergence, but of different lengths, within the limits of a (1 - 2) to (1 - 4) area ratio, give practically the same discharge. In other words, the angle of divergence of the mouthpiece has very much more influence in regaining velocity head than does the length for angles of 10° or greater. The smallest angle used, 5°(1 - 2), gave much the largest coefficient of discharge. A smaller angle would, no doubt, give a larger discharge, as indicated by other experimenters. Possible values of the coefficients are indicated in Fig. 11 to 14 by dotted lines. For further discussion see "Resultsof Earlier Experimenters".

Fig. 11 to 14 show that as the angle of divergence increases the amount of velocity head regained decreases very rapidly ending in a sudden decrease to nearly zero at about 30°.

It will be noted from Table 12 that the value of the coefficient of discharge obtained by experiment with a combination of an entrance and a discharge mouthpiece is larger than that found by calculation using the results obtained from the same mouthpieces when tested separately, except in those cases where the discharge mouthpiece has such a large angle of divergence that little or no velocity head is regained.

It seems evident that the reason for this is the suppression of the contraction at the entrance of the pipe due to the entrance mouthpiece thus allowing the water to approach the discharge mouthpiece in a less troubled condition, that is, with more nearly parallel stream lines. This allows the discharge mouthpiece to reduce the velocity with greater efficiency. This advantage given to the discharge mouthpiece by the entrance mouthpiece is entirely lost if the

discharge mouthpiece has such an angle as to cause a turbulent action of the water under most favorable conditions.

This increase seems to be as high as 15%. This suggests, anew, the importance of lost head due to eddying, impact, etc., and the need for producing smooth flow (ordered motion) at critical sections of flow in order to avoid the destructive influence of the subsequent eddying.

17. Effects of Wing-wall Entrance Mouthpieces on the 12-in. Short Pipe.-- Table 13 gives the values of the coefficients of discharge and loss for a 12-in. diameter short pipe with free discharge. It was not to be expected that a wing-wall mouthpiece of any angle would give a much larger coefficient of discharge than was obtained with the straight-wall or flush entrance since the greater portion of the entrance, with wing-walls of all angles, is a flush entrance.

There seems to be no good reason, however, for the reduction in c as the angle of the wing-wall increases. Since only one run was made with each mouthpiece when the discharge end of the pipe was flowing full, it is very probable that a greater number of experiments would show c to be the same for all mouthpieces and about equal in value to c = 0.78 as compared with c = 0.80, as found for the submerged 6-in. pipe.

The effect of low heads on the contraction and expansion of the stream within the tube, as already discussed, applies for wing-wall approaches. This accounts, it is thought, for the low values as compared with those obtained with the 6-in. submerged short pipe.

18. Comparison with Results of Earlier Experimenters.-- Orifices.-- For circular and square sharp-edged orifices with diameters or sides 4 in. or more, all experiments are in close agreement. The coefficient of discharge may then be taken as 0.600 at least for sizes up

to 4 ft. diameter or side, and heads up to 18.5 ft.

Balch found c to increase slightly with the head for a 1-ft. diameter, circular, and a 1-ft. side, square vertical orifice. Ellis found c to be practically constant for horizontal orifices of the same dimensions. The present experiments show no consistent variation with the head, the range in head, however, is small.

For sharp edged submerged orifices of sizes less than 4 in. diameter or side the results of the various experiments are not quite so consistent. Omitting the experiments of Francis which seem in error due to the weir calculations, the only experiments are those of H. Smith, Jr. These experiments give results, in general, somewhat smaller than those found in the present investigation. The difference, however, rarely exceeds 1% for similar heads. For higher heads Smith's values increase somewhat although the variation is not great.

19. Short Pipes and Mouthpieces.-- For short pipes with entrance flush, the value of c = 0.800 as found in the present experiments is in rather close agreement with that found by Stewart with a 4-ft. square tube, by Balch for a 4-in. diameter tube, both being with submerged discharge, also by Bossut with a vertical tube about 1 in. diameter with free discharge. Nearly all the other experiments, most of which used tubes under 2 in. diameter, show c to be about 0.82, which is the commonly accepted value. It would seem, therefore that the coefficient of discharge for a short pipe with flush entrance should be taken as 0.800, at least for tubes of 4 in. diameter or more with submerged discharge and with heads up to, at least, 4 ft.

For short pipes with inward projecting entrance, the earlier experiments, all of which were with free discharge, are very discordant. The present experiments give c close to 0.78 for both free and

submerged discharge. It is evident that the commonly accepted value c = 0.72 needs revision.

In the case of convergent or entrance mouthpieces, all experiments show that the angle of approach is the most important factor although the angle for maximum discharge or minimum loss of head varies with entrance and discharge conditions. Castel found c = 0.95 to 0.96 for maximum discharge with an angle of mouthpiece of about 7° (14°, total angle), while in the present experiments, the maximum value was c = 0.925 for a 15° mouthpiece (30° total angle) attached to the 6-in. short pipe.

This difference was to be expected, however, With the mouthpiece used by Castel, considerable contraction would take place at the discharge into air with the larger angles, whereas, in the present experiments the 6-in. pipe suppressed this contraction. The flush entrance to the mouthpieces used by Castel would give a larger discharge than for mouthpieces merely projecting into the water as used in experiments herein recorded. Ellis, Francis, Brownlee, and Stewart, with submerged discharge, suppressed the contraction at exit by forming curved approaches and obtained about the same value of c for much larger angles of approach.

Michelotti and Eytelwein for cycloidal entrance mouthpieces and free discharge, together with Freeman for nozzles, seem to give about 0.98 for the coefficient of discharge. The velocity of approach in the nozzle experiments gives quite a different entrance condition from that found with most of the experiments. The details of the apparatus used by Michelotti and Eytelwein are lacking and the high value obtained for c seems somewhat inconsistent with other data.

The experiments most nearly like the ones herein recorded are

those of Stewart, Balch, and Davis and Balch. With a 45°(1 – 1.9) conical entrance mouthpiece on a 4–in. diam. tube, Balch found c = 0.922 as compared with 0.900 for a 45°(1–2) mouthpiece used in the present experiments. Stewart with a (1–4) elliptical entrance mouthpiece (corresponding to about 33°) on a 4 ft. square tube found c equal to about 0.89, although it varied somewhat with the head. Davis and Balch, with a vertical square tube about 1–1/2 ft. on a side having a curved (circular) entrance corresponding to 45°(1–3), found c to increase rather rapidly with the head varying from 0.829 to 0.955 as the head increased from 0.114 to 0.748 ft. For h = 0.511 ft., c was 0.894. This variation with head seems inconsistent with the other experiments.

For divergent mouthpieces alone, there is very little experimental data. With a 2° – 27' (1 – 1.5) mouthpiece (4° – 55' total angle) attached to a tank with sharp edged entrance, Weisbach found c = 0.946. As already discussed, the condition of the water as the mouthpiece receives it, greatly affects the efficiency of the mouthpiece. If this mouthpiece were attached to the discharge end of a pipe, c would probably be somewhat greater than unity. In the present experiments a 5°(1–2) divergent or discharge mouthpiece attached to the 6–in. short pipe gave c = 1.025.

20. Combinations of Entrance and Discharge Mouthpieces.— Table 43 gives in condensed form the results of the most reliable experiments on compound tubes. While the values of c vary considerably with the head in some of the experiments, the values selected are for approximately the same heads, and for purposes of comparison, this is sufficiently accurate.

A study of the table indicates that in the present experiments a considerably larger value of c would have been obtained for a dis-

Table 43.

Combinations of Entrance and Discharge Mouthpieces — Comparison of Earlier Experimenters.

Name	Entrance	Discharge	c	Remarks.
Entelwein	45°(1–4) Circular Approach	2–1/2°(1–3)	1.55	Connected without a straight throat.
Francis	30°(1–1.95) cycloidal "	2–1/2°(1–2)	1.55	Connected by short straight
"	do.	2–1/2°(1–5.3)	2.14	throat.
"	do.	2–1/2°(1–10)	2.35	do.
"	do.	2–1/2°(1–16)	2.35	do.
Brownlee	(1–4) cycloidal Approach	3–1/2°(1–22)	2.20	No straight throat.
Venturi	Not known " "	2–1/4°( )	2.00	" " " (square)
Davis and Balch	45°(1–3) Circular "	14°(1–1.79)	1.03	Short pipe throat, 6 in. long
" " "	45°(1–3) " "	* (1–1.78)	1.00	
The	20°(1–3) Conical "	15°(1–3)	1.14	Short pipe throat, 22–1/2
Present	15°(1–2) " "	15°(1–2)	1.09	in. long.
Experiments	20°(1–2) " "	10°(1–2)	1.15	

*Curved draft tube.

charge mouthpiece of a smaller angle than 5°(10° total angle), probably as high as 1.50 for an angle of 2-1/2°. Also that a 5°(1-3) would show an increase over 5°(1-2). That is, for the small angles the length is important, as would be expected, but for angles 10° or greater, the length of mouthpiece seems to be of little importance, at least within the range of area ratios of (1-2) to (1-4).

21. Summary.— The following summary is given.

Submerged Orifices with Sharp Edges.

1. The coefficient of discharge for submerged sharp-edged orifices is the same for very low heads as for heads of several feet.

2. For circular and square orifices of 10 sq. in. or more, the coefficient of discharge is constant and equal to 0.600. For Orifices of smaller areas, the coefficient increases.

3. Rectangular orifices with the long side from 3 to 12 times the short side, give about 5% larger values for the coefficient of discharge than circular or square orifices of the same area, except for the smaller areas.

4. The difference between the coefficients of discharge for submerged and free discharge is very little, if any, at least for low heads.

Submerged Short Pipes and Mouthpieces.

1. The coefficients of discharge for a 3-in. and a 6-in. pipe with inward projecting entrance was found to be 0.78 for both submerged and free discharge. This corresponds to about 0.61 for the coefficient of loss. For flush entrance the corresponding values are 0.800 and 0.56.

2. The coefficients of discharge and loss for conical

mouthpieces, whether entrance or discharge, attached to a short pipe are the same for extremely low heads as for heads of nearly a foot and probably several feet.

3. If conical entrance or convergent mouthpieces are attached to a pipe the increase in discharge is affected very little by the length of mouthpiece, at least, within the range of area ratios from (1-2) to (1-4). The increase in the discharge is influenced only slightly by angles from 10° to 30° (20° and 60° total angle), the values of the coefficients of discharge and loss being about 0.92 and 0.18 respectively, which are only slightly different fro a still wider range of angles.

4. The coefficients of discharge and loss for divergent or discharge mouthpieces when attached to a short pipe are practically independent of the length of the mouthpiece for angles of 10° (20° total angle) or greater, at least within the range of area ratios from (1-2) to (1-4). Previous experiments, however, indicate that the length has a great influence for angles less than about 5°.

The angle of divergence for any given length has a very great effect upon the discharge. In these experiments the maximum value for the coefficient of discharge was obtained with the smallest angle, 5°(10° total angle), the effect decreasing rapidly to practically zero for a 30°(60° total angle) mouthpiece.

5. The coefficient of discharge for a combination of an entrance and a discharge mouthpiece on a short pipe is greater than would be indicated from the effects of the mouthpieces taken separately, providing the discharge mouthpiece has a small enough angle to regain a considerable velocity head.

Table 3.

Coefficients of Discharge and Loss for Submerged Circular, Square, and Rectangular Orifices with Sharp Edges – as Found by Different Experimenters.

1	2	3	4	5	6	7
Ref. No.	Head ft. h	Average Actual Velocity ft. per sec. v	Coeffi-cient of Dis-charge c	Coeffi-cient of Loss m	No. of Experi-ments	Experimenter
			1-in. Diameter.			
1	0.004	0.11	0.222	2.20	2	
2	0.007	0.40	0.595	1.78	2	
3	0.014	0.59	0.615	1.62	2	
4	0.024	0.81	0.648	1.35	2	
5	0.040	1.06	0.660	1.30	2	
6	0.051	1.12	0.616	1.62	2	Robinson–'09
7	0.070	1.36	0.635	1.40	2	
8	0.079	1.43	0.634	1.46	2	
9	0.155	1.96	0.631	1.52	2	
10	0.233	2.46	0.633	1.50	2	
11	0.345	2.98	0.632	1.50	3	
			1-1/2 – in. Diameter.			
12	0.001	0.12	0.484	3.39	2	
13	0.003	0.24	0.544	2.33	7	
14	0.004	0.34	0.648	1.51	2	
15	0.005	0.37	0.657	1.36	3	
16	0.007	0.46	0.695	1.14	2	Robinson–'09
17	0.014	0.62	0.663	1.34	4	
18	0.021	0.74	0.635	1.52	4	
19	0.034	0.97	0.658	1.32	3	
20	0.044	1.12	0.661	1.28	2	
21	0.063	1.29	0.633	1.50	4	
			2-in. Diameter.			
22	0.008	0.514	0.678	1.11	2	
23	0.013	0.608	0.661	1.27	2	
24	0.019	0.711	0.645	1.41	1	
25	0.043	1.04	0.620	1.59	2	Robinson–'09.
26	0.092	1.49	0.615	1.64	2	
27	0.161	1.99	0.616	1.63	2	
28	0.213	2.27	0.613	1.67	3	
29	0.125	1.74	0.614	1.65	4	Phillips – '07
30	0.181	2.08	0.616	1.63	4	

Table (Continued)

1	2	3	4	5	6	7
			2-in. Diameter (Continued)			
31	0.332	2.89	0.612	1.66	4	
32	0.586	3.79	0.615	1.64	4	
33	0.734	4.20	0.611	1.67	4	Phillips-'07
34	1.074	5.11	0.613	1.66	5	
35	1.435	5.89	0.612	1.66	4	
			4-in. Diameter.			
36	0.006	0.372	0.582	1.95	2	
37	0.007	0.405	0.598	1.80	1	
38	0.008	0.418	0.575	2.02	4	
39	0.009	0.445	0.584	1.93	1	Robinson-'09
40	0.010	0.445	0.562	2.15	2	
41	0.011	0.541	0.637	1.46	1	
42	0.012	0.547	0.617	1.62	2	
43	0.017	0.656	0.617	1.62	3	
44	0.026	0.78	0.598	1.80	3	Seely - '15
45	0.062	1.20	0.602	1.75	4	
46	0.065	1.267	0.616	1.63	2	Robinson-'09
47	0.072	1.314	0.606	1.72	2	
48	0.144	1.86	0.604	1.74	10	
49	0.238	2.36	0.600	1.77	12	
50	0.382	3.02	0.602	1.75	4	Phillips-'07
51	0.509	3.83	0.604	1.74	9	
52	0.700	4.06	0.600	1.77	4	
53	1.134	5.29	0.611	1.68	13	
			6-in. Diameter.			
54	0.005	0.377	0.666	1.27	2	
55	0.006	0.388	0.627	1.56	2	
56	0.009	0.464	0.616	1.66	2	Robinson-'09
57	0.014	0.562	0.594	1.83	4	
58	0.022	0.715	0.600	1.78	2	
59	0.134	1.73	0.600	1.77	7	
60	0.271	2.49	0.600	1.77	4	Phillips-'07
61	0.442	3.17	0.598	1.80	4	
62	0.712	4.02	0.598	1.80	3	
			1/2-in. Square.			
63	0.040	1.098	0.672	1.17	2	
64	0.199	1.732	0.625	1.56	2	Robinson-'09
65	0.178	2.023	0.594	1.80	2	

Table 3 (Continued)

1	2	3	4	5	6	7
			1/2-in. Square (Continued).			
66	0.230	2.42	0.611	1.68	2	Seely - '14
67	1.042	5.15	0.625	1.55	2	Glass Tube Gages. Discharge by wt.
			1-in. Square.			
68	0.027	0.790	0.596	1.79	1	
69	0.030	0.864	0.619	1.59	2	
70	0.056	1.15	0.615	1.64	3	Robinson-'09
71	0.130	1.73	0.600	1.81	2	
72	0.265	2.59	0.621	1.55	3	
			2-in. Square.			
73	0.006	0.420	0.673	1.21	2	
74	0.030	0.885	0.631	1.51	2	
75	0.062	1.24	0.624	1.58	2	Robinson-'09
76	0.077	1.39	0.621	1.59	2	
77	0.325	2.83	0.618	1.60	3	
78	0.113	1.63	0.611	1.68	5	
79	0.164	1.98	0.607	1.71	4	
80	0.335	2.82	0.610	1.68	4	
81	0.509	3.49	0.608	1.70	4	Phillips-'07
82	0.689	4.26	0.608	1.70	7	
83	1.012	4.92	0.610	1.68	4	
84	1.672	6.31	0.610	1.68	4	
			4-in. Square.			
85	0.002	0.277	0.774	0.68	1	
86	0.003	0.282	0.642	1.43	1	
87	0.012	0.515	0.605	1.80	2	Robinson-'09
88	0.021	0.689	0.604	1.73	3	
89	0.034	0.912	0.621	1.56	2	
90	0.036	0.905	0.597	1.79	3	Seely - '14
91	0.039	0.964	0.615	1.68	2	Robinson-'09
92						
92	0.056	1.15	0.604	1.73	4	Seely - '14
93	0.086	0.261	0.604	1.73	4	
94	0.160	1.95	0.602	1.76	11	
95	0.216	2.24	0.602	1.76	4	Phillips-'07
96	0.335	2.78	0.601	1.77	6	
97	0.610	3.73	0.600	1.77	7	
98	1.083	5.03	0.602	1.76	3	

1	2	3	4	5	6	7
			5–1/2 – in. Square.			
99	0.002	0.186	0.522	2.70	2	
100	0.006	0.388	0.612	1.70	2	
101	0.010	0.469	0.587	1.93	2	Robinson–'09
102	0.012	0.517	0.591	1.89	2	
103	0.020	0.673	0.603	1.77	2	
104	0.038	0.935	0.596	1.81	4	
105	0.048	1.06	0.605	1.73	2	Seely – '14
106	0.108	1.60	0.609	1.70	3	
			6–in. x 1/2–in. Rectangular.			
107	0.0030	0.226	0.509	2.87	2	
108	0.0060	0.404	0.651	1.58	2	
109	0.0080	0.441	0.617	1.65	1	
110	0.0278	0.870	0.653	1.55	2	Robinson–'09
111	0.0495	1.161	0.652	1.55	2	
112	0.0554	1.163	0.617	1.64	2	
113	0.1968	2.25	0.635	1.50	2	
114	0.314	2.87	0.635	1.47	2	Seely – '14
115	0.624	4.03	0.632	1.50	3	Head Measured
116	0.992	5.09	0.634	1.49	2	by Glass Tube Cages.
			6–in. x 1–in. Rectangular.			
117	0.006	0.497	0.800	0.57	1	
118	0.007	0.494	0.740	0.85	1	Robinson–'09
119	0.017	0.704	0.673	1.21	2	
120	0.024	0.785	0.636	1.47	2	Seely – '14
121	0.033	0.956	0.656	1.32	1	Robinson–'09
122	0.086	1.510	0.642	1.44	2	
123	0.122	1.75	0.632	1.50	4	Seely – '14
124	0.133	1.84	0.629	1.53	1	
125	0.137	1.88	0.634	1.50	2	Robinson–'09
126	0.193	2.19	0.630	1.52	3	Seely – '14
127	0.250	2.55	0.637	1.48	2	Robinson–'09
128	0.265	2.61	0.635	1.51	1	
129	0.336	2.90	0.628	1.53	5	Seely – '14 (Glass Tube Cage).

Table 3 (Continued).

1	2	3	4	5	6	7
			6–in. x 1–in. Rectangular (Continued)			
130	0.109	1.66	0.626	1.55		
131	0.154	1.98	0.628	1.53		Phillips
132	0.254	2.50	0.621	1.57		
			6–in. x 2–in. Rectangular.			
133	0.0024	0.348	0.889	0.28	1	
134	0.0028	0.350	0.828	0.48	1	
135	0.0102	0.565	0.697	1.07	2	
136	0.0240	0.815	0.657	1.34	2	Robinson–'09
137	0.040	1.016	0.634	1.51	2	
138	0.063	1.27	0.634	1.51	2	
139	0.120	1.76	0.634	1.51	2	

Table 4.

Coefficients of Discharge and Loss for Submerged 6-in. and 2-in. Cylindrical Short Pipe Entrance Flush. As Found by Different Experimenters.

1	2	3	4	5	6	7
Ref. No.	Head ft. h	Actual Av. Velocity ft. per sec. v	Coefficient of Discharge c	Coefficient of Loss m	No. of Experiments Averaged.	Experimenter and Remarks
			6-in. x 22-1/2-in. Short Pipe.			
1	0.0065	0.542	0.840	0.42	2	
2	0.010	0.738	0.915	0.19	2	Robinson-'09
3	0.172	0.960	0.912	0.20	2	90°(1-3) Entrance Mouthpiece.
4	0.0150	0.780	0.804	0.54	4	Seely - '15
5	0.0310	1.140	0.807	0.53	4	90°(1-3) Entrance Mouthpiece.
6	0.0535	1.480	0.798	0.57	4	
7	0.1727	2.65	0.798	0.57	2	
8	0.175		0.813	0.51	5	Seely - '14
9	0.248		0.825	0.47	6	Head Measured by Glass Tube Gages showed considerable variation.
			2-in. x 5-1/2-in. Short Pipe.			
10	0.0097	0.599	0.757	0.74	2	Robinson-'09
11	0.0150	0.760	0.775	0.66	2	After correcting for error in diameter.
12	0.018	0.871	0.808	0.53	2	
13	0.052	1.49	0.815	0.50	2	
14	0.122	2.26	0.808	0.53	2	Correct diameter = 2.085 in.
15	0.328	3.58	0.785	0.62	2	
16	0.252	3.29	0.815	0.49	3	Seely - '14
17	0.450	4.42	0.819	0.48	2	Measured by Glass Tube gages, considerable variation.
18	0.633	5.30	0.829	0.45	3	
19	0.803	6.07	0.826	0.46	3	

Table 5.

Coefficients of Discharge and Loss for a Submerged 6-in. and 5-in. Short Pipe with Entrance Inward Projecting — as Found by Different Experimenters.

1	2	3	4	5	6	7
Ref. No.	Head ft. h	Actual Av. Velocity ft. per sec. v	Coefficient of Discharge c	Coefficient of Loss m	No. of Experiments Averaged.	Experimenter
1	0.003	0.326	0.742	0.83	2	
2	0.0049	0.405	0.723	0.92	2	
3	0.0069	0.498	0.748	0.79	2	Robinson—'09
4	0.008	0.577	0.804	0.55	2	
5	0.012	0.701	0.800	0.57	1	
6	0.0139	0.757	0.801	0.57	2	
7	0.004	0.405	0.802	0.57	2	Robinson—'09
8	0.008	0.572	0.789	0.58	2	90° (1-3) Flange
9	0.0196	0.894	0.798	0.58	2	Discharge End.
10	0.0224	0.972	0.810	0.53	2	
11	0.019	0.81	0.725	0.85	2	
12	0.034	1.15	0.78	0.65	3	
13	0.165	2.54	0.785	0.62	2	Robinson—'06
14	0.296	3.41	0.78	0.65	3	
15	0.437	4.23	0.79	0.60	4	
16	0.009	0.54	0.735	0.85	2	
17	0.022	0.95	0.800	0.57	1	Robinson—'06
18	0.056	1.49	0.788	0.61	2	90° (1-3) Flange
19	0.137	2.40	0.810	0.52	1	on Discharge
20	0.210	2.94	0.800	0.57	2	End.
21	0.220	3.01	0.800	0.57	1	
22	0.296	3.47	0.795	0.59	2	
23	0.357	3.83	0.802	0.56	2	
24	0.476	4.45	0.802	0.56	2	
25	0.015	0.67	0.678	1.18	2	
26	0.020	0.84	0.722	0.92	2	
27	0.033	1.47	0.76	0.75	3	
28	0.061	1.57	0.77	0.69	3	
29	0.088	1.85	0.78	0.65	2	Wiley—'04
30	0.125	2.22	0.78	0.65	2	
31	0.226	3.07	0.78	0.65	2	
32	0.383	3.88	0.788	0.61	2	
33	0.746	4.65	0.78	0.65	2	

Table 5 (Continued)

1	2	3	4	5	6	7
34	0.10	1.86	0.74	0.82	2	Ireland—'03 Discharge measured over 3—ft. weir.
35	0.33	3.43	0.75	0.80	2	
36	1.00	6.34	0.795	0.58	2	
37	0.0152		0.780	0.64	5	
38	0.0190		0.785	0.62	4	
39	0.0327		0.784	0.62	3	Seely—'15
40	0.0745		0.783	0.63	4	
41	0.4420		0.783	0.63	3	
42	0.040		0.804	0.54	4	Seely—'14 Head measured by Class Tube gages.
43	0.059		0.798	0.57	2	
44	0.069		0.801	0.55	5	
45	0.119		0.794	0.58	5	
46	0.117		0.793	0.59	3	90° (1—3) Flange on Discharge End.
			3—in. x 12—in. Short Pipe.			
47	0.1962		0.785	0.62	2	Seely — '15
48	0.5030		0.788	0.61	3	

Table 6.

Coefficients of Discharge and Loss for a Submerged 6-in. Short Pipe having (1-2) Mouthpieces of Various Degrees as Found by Different Experimenters.

1	2	3	4	5	6	7
Ref. No.	Head ft. h	Actual Av. Velocity ft. per sec. v	Coeffi-cient of Dis-charge c	Coeffi-cient of Loss m	No. of Experi-ments Aver-aged.	Experimenter
			5°(1-2) Entrance Mouthpieces.			
1	0.002	0.295	0.835	0.48	2	
2	0.004	0.501	0.991	0.02	2	Robinson-'09
3	0.005	0.533	0.946	0.13	4	
4	0.010	0.750	0.947	0.10	2	
5	0.033	1.27	0.873	0.31	4 h.g.	
6	0.036	1.36	0.900	0.23	4 g.g.	
7	0.075	2.20	0.908	0.21	2 g.g.	
8	0.088	2.16	0.904	0.22	4 g.g.	Seely - '14
9	0.170	2.94	0.887	0.27	3 h.g.&f.	
10	0.198	3.13	0.876	0.30	5 h.g.	
11	0.352	4.27	0.899	0.24	3 h.g.&f.	
			5°(1-2) Discharge Mouthpieces.			
12	0.003	0.460	1.048	-0.085	2	
13	0.0044	0.563	1.065	-0.113	2	
14	0.0063	0.683	1.078	-0.122	2	Robinson-'09
15	0.008	0.759	1.059	-0.106	1	
16	0.009	0.757	0.990	+0.020	3	
17	0.012	0.845	0.955	+0.10	2	Robinson-'06
18	0.031	1.42	1.010	-0.02	2	
19	0.0593	1.98	1.015	-0.03	4	Seely - '14
20	0.092	2.47	1.02	-0.04	2	Robinson-'06
21	0.117	2.84	1.04	-0.08	2	
22	0.140	3.03	1.01	-0.02	3	Seely - '14
23	0.148	3.26	1.06	-0.105	2	
24	0.250	4.20	1.05	-0.09	2	Robinson-'09
25	0.315	4.65	1.03	-0.06	1	
26	0.342	4.73	1.03	-0.06	3	

h.g. = hook gage; g.g. = glass tube gage; f = float in pit.

1	2	3	4	5	6	7
			10°(1–2) Entrance Mouthpiece.			
27	0.004	0.477	0.942	0.135	2	
28	0.0053	0.550	0.962	0.120	2	
29	0.0085	0.673	0.928	0.170	2	Robinson–'09
30	0.010	0.779	0.971	0.060	2	
31	0.011	0.745	0.885	0.285	2	
32	0.0095	0.575	0.740	0.833	2	
33	0.015	0.845	0.860	0.360	2	
34	0.060	1.77	0.900	0.24	2	
35	0.217	3.42	0.913	0.202	2	Wiley – '04
36	0.254	3.72	0.920	0.185	2	
37	0.500	5.25	0.925	0.170	2	
38	0.570	5.58	0.925	0.170	2	
39	1.120	7.70	0.910	0.210	2	Ireland –'03
40	1.810	9.88	0.915	0.195	2	Discharge in Air.
			10°(1–2) Discharge Mouthpiece.			
41	0.0025	0.355	0.890	0.27	2	
42	0.004	0.468	0.923	0.18	2	
43	0.0052	0.582	1.014	–0.025	2	Robinson–'09
44	0.0068	0.654	0.999	0.00	2	
45	0.008	0.735	1.03	–0.06	2	
46	0.009	0.738	0.972	0.07	1	
47	0.0085	0.54	0.732	0.87	2	
48	0.038	1.39	0.890	0.26	1	Wiley – '04
49	0.038	1.47	0.950	0.11	3	Seely – '14
50	0.156	3.00	0.945	0.12	2	
51	0.356	4.54	0.948	0.11	2	Wiley – '04
52	0.412	4.89	0.943	0.12	2	
53	0.632	0.614	0.962	0.08	2	
			15°(1–2) Discharge Mouthpiece.			
54	0.0030	0.401	0.908	0.21	4	
55	0.0039	0.470	0.946	0.11	4	
56	0.0047	0.528	0.950	0.11	6	Robinson–'09
57	0.0062	0.562	0.895	0.24	4	
58	0.0142	0.860	0.899	0.24	3	
59	0.011	0.650	0.790	0.60	2	
60	0.088	2.13	0.887	0.28	2	
61	0.254	3.71	0.915	0.20	2	Wiley – '04
62	0.423	4.85	0.925	0.17	2	
63	0.765	6.40	0.915	0.20	2	

1	2	3	4	5	6	7
			15°(1–2) Entrance Mouthpiece.			
64	0.0033	0.426	0.927	0.17	2	
65	0.006	0.578	0.927	0.17	2	Robinson–'09
66	0.008	0.682	0.952	0.11	2	
67	0.0094	0.730	0.938	0.15	2	
68	0.010	0.655	0.802	0.56	2	Wiley – '04
69	0.059	1.73	0.890	0.25	3	
70	0.060	1.84	0.925	0.17	4	Seely – '14
71	0.282	3.80	0.893	0.25	3	Wiley – '04
72	0.753	6.50	0.930	0.16	2	
73	0.10	1.97	0.775	0.66	2	Ireland – '03
74	0.25	3.46	0.875	0.305	2	Discharge meas–
75	1.02	7.55	0.935	0.14	2	ured over 3–ft. weir
76	0.080	6.63	0.930	0.16	2	Ireland – '03
77	1.14	7.95	0.935	0.14	2	Discharge in Air.
78	1.77	9.86	0.924	0.17	3	" measured in pit.
			20°(1–2) Entrance Mouthpiece.			
79	0.004	0.440	0.870	0.33	3	
80	0.0059	0.565	0.919	0.18	3	Robinson–'09
81	0.0068	0.608	0.924	0.17	5	
82	0.0179	0.994	0.927	0.17	2	
83	0.008	0.600	0.838	0.43	2	
84	0.020	1.05	0.920	0.18	1	
85	0.060	1.79	0.915	0.19	1	Wiley – '04
86	0.138	2.75	0.920	0.18	1	
87	0.232	3.60	0.927	0.16	2	
88	0.427	4.91	0.927	0.16	2	
89	0.785	6.52	0.920	0.18	2	Ireland – '03
90	1.110	7.67	0.910	0.21	2	Dischg. in Air.
91	1.830	9.85	0.910	0.21	2	" Measured in pit.
			20°(1–2) Discharge Mouthpiece.			
92	0.0042	0.424	0.816	0.50	2	
93	0.007	0.570	0.847	0.40	3	
94	0.0087	0.670	0.900	0.24	3	Robinson–'09
95	0.0131	0.806	0.880	0.30	2	
96	0.0152	0.859	0.870	0.32	2	
97	0.011	0.72	0.855	0.37	2	
98	0.029	1.20	0.880	0.30	2	Wiley – '04
99	0.060	1.78	0.910	0.21	2	

1	2	3	4	5	6	7
			20°(1–2) Discharge Mouthpiece (Continued)			
100	0.112	2.41	0.900	0.24	2	
101	0.185	3.07	0.890	0.27	2	Wiley – '04
102	0.500	5.18	0.910	0.21	2	
			30°(1–2) Entrance Mouthpiece.			
103	0.0032	0.448	0.997	0.065	4	
104	0.0070	0.602	0.899	0.25	3	
105	0.0083	0.675	0.924	0.17	2	Robinson–'09
106	0.0100	0.771	0.964	0.08	2	
107	0.0142	0.875	0.917	0.19	2	
108	0.014	0.79	0.838	0.43	2	Wiley – '04
109	0.041	1.45	0.900	0.25	2	
110	0.0818	2.11	0.919	0.18	2	Seely – '14
111	0.082	2.07	0.880	0.29	2	Wiley – '04
112	0.390	4.61	0.923	0.18	3	
113	1.12	7.85	0.925	0.17	2	Ireland – '03
114	1.74	9.75	0.920	0.18	1	Discharge into
115	1.81	9.77	0.910	0.21	1	Air.
			30°(1–2) Discharge Mouthpiece.			
116	0.0046	0.486	0.891	0.26	3	
117	0.0059	0.458	0.714	0.98	2	
118	0.0068	0.542	0.821	0.49	2	Robinson–'09
119	0.0098	0.670	0.846	0.40	2	
120	0.0127	0.735	0.815	0.50	2	
121	0.0167	0.838	0.804	0.55	2	
122	0.0804	1.83	0.792	0.59	3	Seely – '14
123	0.2715	3.35	0.802	0.55	4	
			45°(1–2) Entrance Mouthpiece.			
124	0.0062	0.545	0.865	0.35	2	
125	0.0088	0.620	0.829	0.46	2	
126	0.0115	0.737	0.858	0.38	3	Robinson–'09
127	0.0140	0.849	0.897	0.25	2	
128	0.0153	0.868	0.873	0.32	2	
129	0.0462	1.55	0.902	0.23	2	Seely – '14
130	0.009	0.565	0.750	0.78	2	
131	0.050	1.49	0.840	0.42	1	
132	0.104	2.28	0.880	0.29	2	
133	0.325	4.09	0.890	0.28	2	Wiley – '04
134	0.560	5.52	0.915	0.20	2	
135	0.850	6.77	0.920	0.18	2	

1	2	3	4	5	6	7
			45°(1–2) Entrance Mouthpiece. (Continued)			
136	1.10	7.61	0.905	0.22	2	Ireland – '03
137	1.14	7.51	0.875	0.30	2	Discharge in
138	1.76	9.45	0.893	0.25	3	Air.
			45°(1–2) Discharge Mouthpiece.			
139	0.0073	0.560	0.815	0.51	2	
140	0.0144	0.755	0.800	0.58	3	
141	0.0160	0.829	0.818	0.50	2	Robinson–'09
142	0.0180	0.885	0.795	0.59	2	
143	0.0521	1.44	0.790	0.60	4	Seely – '14
144	0.010	0.58	0.708	1.00	2	
145	0.058	1.49	0.775	0.67	1	
146	0.115	2.13	0.780	0.64	2	Wiley – '04
147	0.525	4.62	0.800	0.57	2	
148	0.905	6.10	0.800	0.57	2	
			60°(1–2) Entrance Mouthpiece.			
149	0.0047	0.500	0.911	0.21	3	
150	0.0096	0.697	0.882	0.29	3	Robinson–'09
151	0.0132	0.822	0.891	0.26	2	
152	0.0798	2.01	0.889	0.26	2	Seely – '14
153	1.14	7.51	0.885	0.28	2	Ireland – '03
154	1.85	9.58	0.880	0.29	2	Discharge in Air.
			60°(1–2) Discharge Mouthpiece.			
155	0.0086	0.567	0.766	0.71	3	
156	0.017	0.794	0.761	0.73	2	Robinson–'09
157	0.018	0.837	0.774	0.65	2	
158	0.010	0.56	0.678	1.21	2	
159	0.056	1.39	0.735	0.85	2	
160	0.146	2.38	0.778	0.66	2	Wiley – '04
161	0.500	4.46	0.778	0.66	2	
162	0.875	5.98	0.805	0.55	2	
163	0.0600	1.55	0.786	0.62	2	
164	0.1035	2.03	0.787	0.61	2	Seely – '14
165	0.1940	2.79	0.792	0.59	2	
166	0.2605	3.27	0.796	0.58	2	

Table 7.

Coefficients of Discharge and Loss for a Submerged 6-in. Short Pipe having (1-3) and (1-4) Mouthpieces of Various Degrees as Found by Different Experimenters.

1	2	3	4	5	6	7
Ref. No.	Head ft. h	Actual Av. Velocity ft. per sec. v	Coefficient of Discharge c	Coefficient of Loss m	No. of Experiments Averaged.	Experimenter.
			10° (1-3) Entrance Mouthpiece.			
1	0.003	0.358	0.817	0.50	2	
2	0.0094	0.682	0.880	0.30	3	Robinson-'09
3	0.0114	0.760	0.888	0.255	2	
4	0.014	0.871	0.916	0.195	2	
5	0.021	1.07	0.922	0.173	5	Seely - '14
6	0.096	2.30	0.928	0.160	3	
			10° (1-3) Discharge Mouthpiece.			
7	0.004	0.491	0.975	0.06	2	
8	0.0094	0.707	0.910	0.21	2	Robinson-'09
9	0.0117	0.792	0.915	0.19	3	
10	0.0135	0.831	0.893	0.26	2	
11	0.012	0.68	0.780	0.64	1	Robinson-'06
12	0.025	1.17	0.920	0.19	2	
13	0.037	1.48	0.956	0.09	3 v.s.	Seely - '14
14	0.053	1.74	0.940	0.12	1	Robinson-'06
15	0.053	1.76	0.956	0.09	3	Seely - '14
16	0.093	2.51	1.03	-0.06	3	Robinson-'06
17	0.100	2.39	0.951	0.10	2 v.s.	Seely - '14
18	0.192	3.55	1.01	-0.02	2	Robinson
19	0.192	3.50	0.997	0.004	3 v.f.	Seely - '14
20	0.188	3.37	0.967	0.06	2 v.s.	
21	0.335	4.70	1.02	-0.04	3	Robinson

v.s. = vortex suppressed. v.f. = vortex formed.

1	2	3	4	5	6	7
			15°(1–3) Entrance Mouthpiece.			
22	0.0094	0.748	0.960	0.08		
23	0.0110	0.783	0.934	0.15		
24	0.0145	0.906	0.940	0.14		
25	0.0165	0.970	0.941	0.14		
26	0.0497	1.65	0.921	0.18	3 v.n.	
27	0.1920	3.25	0.924	0.17	4 v.n.	Seely – '14.
28	0.1921	3.16	0.904	0.22	2 v.s.	
			15°(1–3) Discharge Mouthpiece.			
29	0.0023	0.316	0.824	0.48	2	
30	0.0114	0.795	0.928	0.17	2	Robinson–'09
31	0.0138	0.864	0.916	0.20	2	
32	0.0172	0.948	0.901	0.23	4	
33	0.010	0.80	0.82	0.49	1	Robinson–'06
34	0.056	1.80	0.950	0.10	2	
35	0.0589	1.76	0.901	0.23	2	Seely – '14
36	0.114	2.55	0.945	0.11	2	
37	0.1945	3.24	0.914	0.20	2	Seely – '14
38	0.1885	3.20	0.920	0.18	1	
39	0.224	3.54	0.935	0.14	2	
40	0.263	3.82	0.930	0.16	2	Robinson–'06
41	0.282	4.03	0.948	0.11	3	
42	0.334	4.40	0.950	0.11	3	
			20°(1–3) Discharge Mouthpiece.			
43	0.006	0.570	0.918	0.19	2	
44	0.0078	0.648	0.911	0.20	2	
45	0.0097	0.698	0.886	0.28	2	Robinson–'09
46	0.0150	0.882	0.883	0.30	2	
47	0.0177	0.950	0.891	0.26	2	
48	0.008	0.51	0.71	0.98	2	
49	0.010	0.71	0.87	0.32	2	Robinson–'06
50	0.028	1.17	0.870	0.32	2	
51	0.044	1.45	0.872	0.31	2	Seely – '14
52	0.048	1.44	0.875	0.30	2	
53	0.140	2.60	0.870	0.32	2	Robinson–'06
54	0.196	3.16	0.890	0.26	2	
55	0.2195	3.25	0.892	0.25	2	Seely – '15.

v.n. = vortex noticed.

1	2	3	4	5	6	7
			20°(1–3) Discharge Mouthpiece. (Continued)			
56	0.269	3.76	0.895	0.26	2	Robinson–'06
57	0.342	4.32	0.925	0.17	2	
			20°(1–4) Discharge Mouthpiece.			
58	0.0071	0.627	0.930	0.16	2	
59	0.0105	0.691	0.842	0.41	2	
60	0.0133	0.814	0.880	0.29	2	Robinson–'09
61	0.0148	0.870	0.889	0.27	2	
62	0.0181	0.966	0.900	0.25	2	
63	0.025	1.15	0.908	0.21	2	
64	0.055	1.68	0.899	0.24	2	
65	0.101	2.32	0.912	0.20	2	
66	0.132	2.67	0.918	0.18	2	Robinson–'06
67	0.258	3.81	0.935	0.14	2	
68	0.354	4.45	0.935	0.14	1	
69	0.465	5.13	0.937	0.13	2	
			20°(1–3) Entrance Mouthpiece.			
70	0.005	0.527	0.930	0.16	2	
71	0.0113	0.785	0.921	0.19	3	Robinson–'09
72	0.0142	0.860	0.900	0.24	2	
73	0.0170	0.958	0.916	0.20	3	
74	0.018	0.98	0.905	0.23	1	
75	0.044	1.52	0.915	0.20	2	Robinson–'06
76	0.080	2.09	0.920	0.18	1	
77	0.098	2.34	0.930	0.16	2	
78	0.1012	2.36	0.924	0.17	4	Seely – '15
79	0.137	2.75	0.930	0.16	2	
80	0.178	3.17	0.940	0.12	2	
81	0.228	3.59	0.940	0.12	2	Robinson–'06
82	0.259	3.72	0.915	0.20	1	
83	0.358	4.48	0.935	0.14	2	
			20°(1–4) Entrance Mouthpiece.			
84	0.0073	0.0582	0.853	0.38		
85	0.0107	0.728	0.880	0.30		Robinson–'09
86	0.0146	0.895	0.926	0.17		
87	0.0160	0.942	0.929	0.16		
88	0.1870	3.22	0.930	0.15	2	Seely –'15
89	0.1906	3.25	0.927	0.16		
			30°(1–3) Discharge Mouthpiece.			
90	0.013	0.67	0.730	0.89	1	Robinson–'06

30°(1–3) Discharge Mouthpiece. (Continued)

91	0.026	1.04	0.800	0.58	2	
92	0.067	1.68	0.820	0.50	2	
93	0.143	2.48	0.820	0.48	2	
94	0.168	2.63	0.805	0.54	2	Robinson–'06
95	0.242	3.20	0.810	0.52	2	
96	0.385	4.04	0.825	0.47	1	
97	0.520	4.72	0.815	0.51	2	

45°(1–3) Entrance Mouthpiece.

98	0.0042	0.520	1.012	–0.026	2	
99	0.0068	0.590	0.898	0.25	2	Robinson–'09
100	0.0118	0.773	0.890	0.27	2	
101	0.0180	0.968	0.900	0.24	2	
102	0.1164	2.50	0.912	0.20	7	Seely – '15
103	0.3223	4.14	0.906	0.22	3	

45°(1–3) Discharge Mouthpiece.

104	0.0071	0.542	0.802	0.56	2	
105	0.0092	0.620	0.806	0.54	2	
106	0.0124	0.714	0.800	0.56	2	Robinson–'09
107	0.0152	0.806	0.812	0.52	3	
108	0.0233	0.986	0.806	0.54	2	
109	0.011	0.600	0.720	0.93	1	
110	0.030	1.13	0.810	0.52	2	
111	0.074	1.77	0.815	0.51	2	
112	0.130	2.34	0.805	0.55	2	
113	0.176	2.69	0.800	0.57	2	Robinson–'06
114	0.205	2.92	0.805	0.55	2	
115	0.282	3.39	0.800	0.57	2	
116	0.350	3.76	0.795	0.59	2	
117	0.452	4.26	0.792	0.60	2	
118	0.507	4.67	0.796	0.58	2	

90°(1–3) Entrance Mouthpiece, see Table 4.

90°(1–3) Discharge Mouthpiece, see Table 5.

Table 8.

Coefficients of Discharge and Loss for a Submerged 6-in. Short Pipe with Various Combinations of Mouthpieces — as Found by Different Experimenters.

1	2	3	4	5	6	7	8	9
Ref. No.	Mouthpieces Entrance End.	Mouthpieces Discharge End.	Head ft. h	Average Actual Velocity ft. per sec. v	Coefficient of Discharge c	Coefficient of Loss m	No. of Exp. Av.	Experimenter.
1	15°	15°	0.011	0.76	0.905	0.22	2	
2	(1-2)	(1-2)	0.034	1.48	1.002	0.00	2	
3			0.043	1.75	1.05	-0.09	1	Wiley-'04
4			0.069	2.30	1.085	-0.15	2	
5			0.318	4.97	1.094	-0.16	4	
6			0.550	5.93	1.137	-0.22	2	
7	20°	5°	0.0028	0.427	1.01	-0.01	1	
8	(1-2)	(1-2)	0.0036	0.559	1.12	-0.30	2	
9			0.0042	0.659	1.27	-0.47	1	Robinson-'09
10			0.0055	0.812	1.56	-0.45	2	
11			0.0080	0.918	1.34	-0.44	2	
12			0.1548	4.26	1.35	-0.45	5	Seely-'15
13	20°	5°	0.012	1.104	1.27	-0.328	2	
14	(1-3)	(1-2)	0.027	1.65	1.25	-0.36	2	
15			0.041	2.18	1.345	-0.44	2	
16			0.060	2.64	1.35	-0.45	2	Robinson-'06
17			0.092	3.28	1.355	-0.46	2	
18			0.132	3.98	1.365	-0.47	2	
19			0.162	4.43	1.375	-0.48	2	
20			0.187	4.88	1.405	-0.49	2	
21	20°	10°	0.008	0.68	0.955	+0.10	2	
22	(1-2)	(1-2)	0.022	1.22	1.02	-0.04	2	
23			0.050	1.56	1.12	-0.20	1	
24			0.071	2.46	1.155	-0.25	2	Wiley-'04
25			0.178	3.90	1.15	-0.24	2	
26			0.322	5.16	1.15	-0.24	1	
27			0.496	6.80	1.18	-0.28	1	
28	30°	10°	0.011	0.725	1.10	-0.172	2	Wiley-'04
29	(1-2)	(1-2)						
29			0.0229	1.50	1.25	-0.36	2	Seely-'15
30			0.034	1.70	1.13	-0.23	3	Wiley-'04
31			0.065	2.36	1.16	-0.25	2	

Table 8. (Continued).

1	2	3	4	5	6	7	8	9
32	30°	10°	0.186	4.16	1.21	−0.31	2	
33	(1–2)	(1–2)	0.303	5.30	1.20	−0.30	2	Wiley–'04
34	Cont.	Cont.	0.500	6.95	1.23	−0.34	2	
35	20°	15°	0.004	0.568	1.13	−0.21	2	
36	(1–3)	(1–3)	0.008	0.798	1.11	−0.19	2	
37			0.0098	0.866	1.10	−0.18	2	Robinson–'09
38			0.0114	0.995	1.15	−0.26	1	
39			0.0122	1.001	1.13	−0.21	1	
40			0.2022	4.17	1.154	−0.25	3	Seely–'15
41	30°	30°	0.036	1.38	0.900	0.24	2	Wiley–'04
42	(1–2)	(1–2)	0.0717	2.02	0.940	0.13	2	Seely–'15
43			0.097	2.23	0.890	0.26	2	Wiley–'04
44			0.156	2.98	0.944	0.12	2	Seely–'15
45			0.373	4.60	0.932	0.15	2	
46			0.465	5.49	0.935	0.15	2	Wiley–'04
47			0.742	6.48	0.935	0.15	2	
48	45°	45°	0.011	0.64	0.77	0.69	2	Wiley–'04
49	(1–2)	(1–2)	0.044	1.41	0.83	0.45	1	
50			0.0525	1.68	0.912	0.20	2	Seely–'15
51			0.108	2.30	0.865	0.34	2	
52			0.337	4.18	0.892	0.26	2	Wiley–'04
53			0.466	5.12	0.912	0.21	2	
54			0.828	6.71	0.915	0.20	2	
55	60°	60°	0.011	0.59	0.708	1.00	2	
56	(1–2)	(1–2)	0.017	0.77	0.740	0.82	1	
57			0.111	2.30	0.867	0.54	3	Wiley–'04
58			0.432	4.67	0.888	0.27	2	
59			0.864	6.67	0.895	0.25	2	

Table 9.

Coefficients of Discharge and Loss for Circular, Square and Rectangular Submerged Orifices with Sharp Edges. Velocities under 6 ft. per sec.

Shape Orifice	Size in.	Coefficient of Discharge c	Coefficient of Loss m
Circular	1 diameter	0.632	1.50
	1-1/2 "	- -	
	2 "	0.615	1.64
	4 "	0.603	1.74
	6 "	0.600	1.78
Square	1/2 x 1/2	0.615	1.64
	1 x 1	0.612	1.67
	2 x 2	0.610	1.68
	4 x 4	0.602	1.75
	5-1/2 x 5-1/2	0.600	1.78
Rectangular	1/2 x 6	0.634	1.49
	1 x 6	0.634	1.49
	2 x 6	0.634	1.49

Table 10.

Coefficients of Discharge and Loss for a Submerged 6-in. x 22-1/2-in. Cylindrical Short Pipe with (1-2) Conical Mouthpieces for Heads Below 0.8 ft. and Velocities Below 6 ft. per sec.

Mouthpieces Entrance	Discharge	Coefficient of Discharge c	Coefficient of Loss m	Gain in c due to Entrance Mouthpieces. c_r	Gain in c due to Discharge Mouthpieces. c_n	Reduction in m_p due to Entrance Mouthpieces m_r	Reduction in m_p due to Discharge Mouthpieces. n
0° Inward Proj.	0°	0.785	0.610	0.000	0.000	0.000	0.000
5°(1-2)		0.900	0.253	0.115		0.377	
	5°(1-2)	1.025	-0.047		0.240		0.657
10°(1-2)		0.920	0.178	0.135		0.432	
	10°(1-2)	0.950	0.105		0.165		0.505
15°(1-2)		0.925	0.162	0.140		0.448	
	15°(1-2)	0.915	0.190		0.120		0.420
20°(1-2)		0.920	0.178	0.135		0.432	
	20°(1-2)	0.890	0.258		0.105		0.352
30°(1-2)		0.915	0.191	0.130		0.419	
	30°(1-2)	0.800	0.560		0.015		0.050
45°(1-2)		0.895	0.248	0.110		0.378	
	45°(1-2)	0.800	0.560		0.015		0.050
60°(1-2)		0.890	0.258	0.105		0.352	
	60°(1-2)	0.785	0.610		0.000	0.000	0.000

Table //.

Coefficients of Discharge and Loss for a Submerged 6-in. x 22-1/2-in. Cylindrical Short Pipe with (1-3) and (1-4) Conical Mouthpieces for Heads Below 0.8 ft. and Velocities Below 6 ft. per sec.

Mouthpieces Entrance	Mouthpieces Discharge	Coefficient of Discharge c	Coefficient of Loss m	Gain in c due to Entrance Mouthpieces. c_Y	Gain in c due to Discharge Mouthpieces. c_n	Reduction in m_p due to Entrance Mouthpieces. m_Y	Reduction in m_p due to Discharge Mouthpieces. n
0° Inward Proj. 0°		0.785	0.610	0.000	0.000	0.000	0.000
10°(1-3)		0.915	0.190	0.130		0.420	
	10°(1-3)	0.960	0.080		0.175		0.530
15°(1-3)		0.925	0.162	0.140		0.458	
	15°(1-3)	0.915	0.190		0.130		0.420
20°(1-3)		0.925	0.162	0.140		0.448	
	20°(1-3)	0.890	0.258		0.105		0.352
	30°(1-3)	0.810	0.520		0.025		0.080
45°(1-3)		0.900	0.233	0.115		0.377	
	45°(1-3)	0.800	0.560		0.015		0.050
90°(1-3) Flush		0.800	0.560	0.015		0.050	
	90°(1-3)	0.785	0.610		0.000		0.000
20°(1-4)		0.925	0.162	0.140		0.448	
	20°(1-4)	0.900	0.233		0.115		0.377

Table 12.

Coefficients of Discharge and Loss for a 6-in. x 22-1/2 - in. Short Pipe with Various Combinations of Mouthpieces for Heads below 0.80 ft. and Velocities below 7 ft. per sec.

Ref. No.	Mouthpieces Entrance	Mouthpieces Discharge	Coefficient of Discharge from Experiment c	Coefficient of Loss from Experiment m	Coefficient of Discharge (Calculated). $c_c=c_p+c_r+c_n$	Coefficient of Loss (Calculated). $m_c=m_p-m_r-n$.
1	15°(1-2)	15°(1-2)	1.09	−0.260	1.045	−0.258
2	20°(1-2)	5°(1-2)	1.35	−0.453	1.160	−0.381
3	30°(1-3)	5°(1-2)	1.36	−0.460	1.165	−0.595
4	20°(1-2)	10°(1-2)	1.15	−0.245	1.085	−0.327
5	20°(1-3)	15°(1-3)	1.14	−0.234	1.055	−0.308
6	30°(1-2)	10°(1-2)	1.20	−0.306	1.075	−0.293
7	30°(1-2)	30°(1-2)	0.935	+0.142	0.925	+0.150
8	45°(1-2)	45°(1-2)	0.910	+0.200	0.910	+0.182
9	60°(1-2)	60°(1-2)	0.890	+0.258	0.890	+0.258

Table 13

Coefficients of Discharge and Loss for a 12-in. diameter Short Pipe with Wing-Wall Entrance Mouthpieces. Discharge in Air — Measured over 3-ft. Weir. Discharge End Flowing Full.

Wing-Wall Mouthpiece	Head ft. h	Actual Av. Velocity ft. per sec. v	Coefficient of Discharge c	Coefficient of Loss m	No. of Experiments Averaged
None Inward Projecting	0.96	5.40	0.69	1.10	1
0°	1.23	6.94	0.79	0.60	1
15°	1.25	6.92	0.78	0.60	1
30°	1.21	6.61	0.76	0.73	1
45°	1.11	6.20	0.74	0.83	1
90°	1.00	5.60	0.71	0.98	2
Straight-Wall Flush	1.31	7.29	0.80	0.56	1

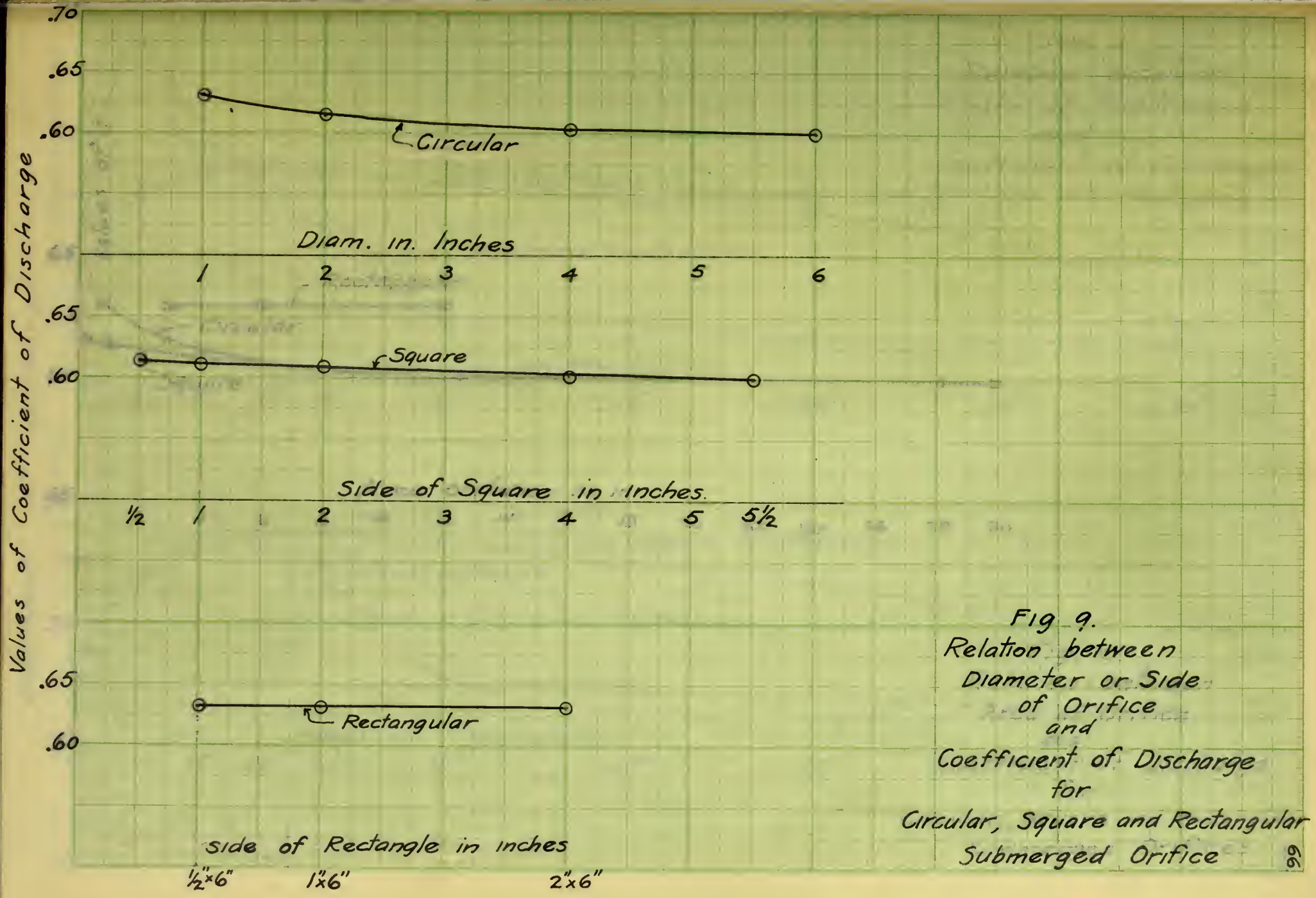

Fig 9.
Relation between
Diameter or Side
of Orifice
and
Coefficient of Discharge
for
Circular, Square and Rectangular
Submerged Orifice

Fig 4.
Relation between Diameter or Side of Orifice and Coefficient of Discharge for Circular, Square and Rectangular Orifices

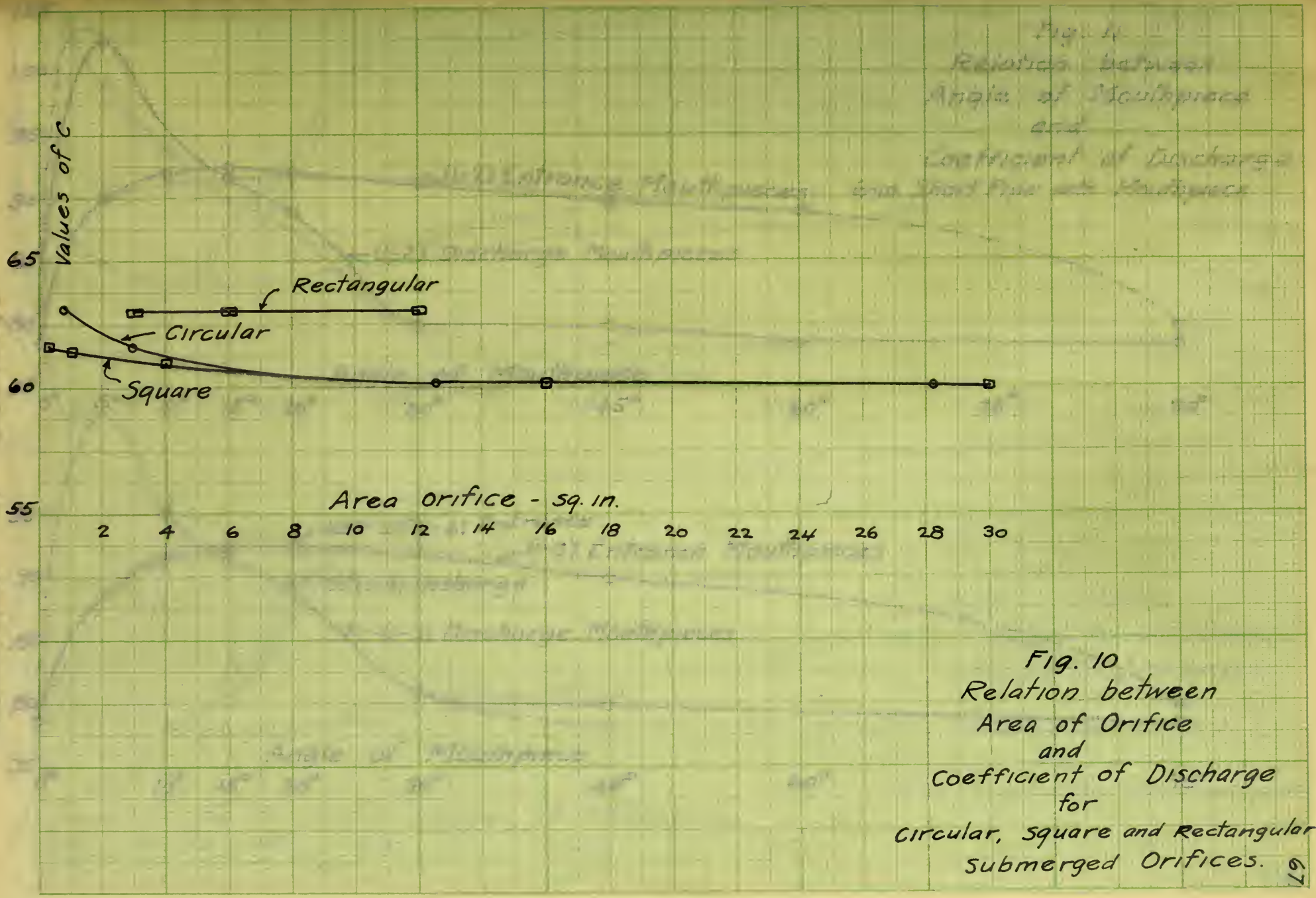

Fig. 10
Relation between
Area of Orifice
and
Coefficient of Discharge
for
Circular, Square and Rectangular
Submerged Orifices.

Engineer's Office.
Circular, Drains and Sewerage
Department

Fig. 13

Relation between
outlet area
and
consumption to discharge
at
Engineer's Office.

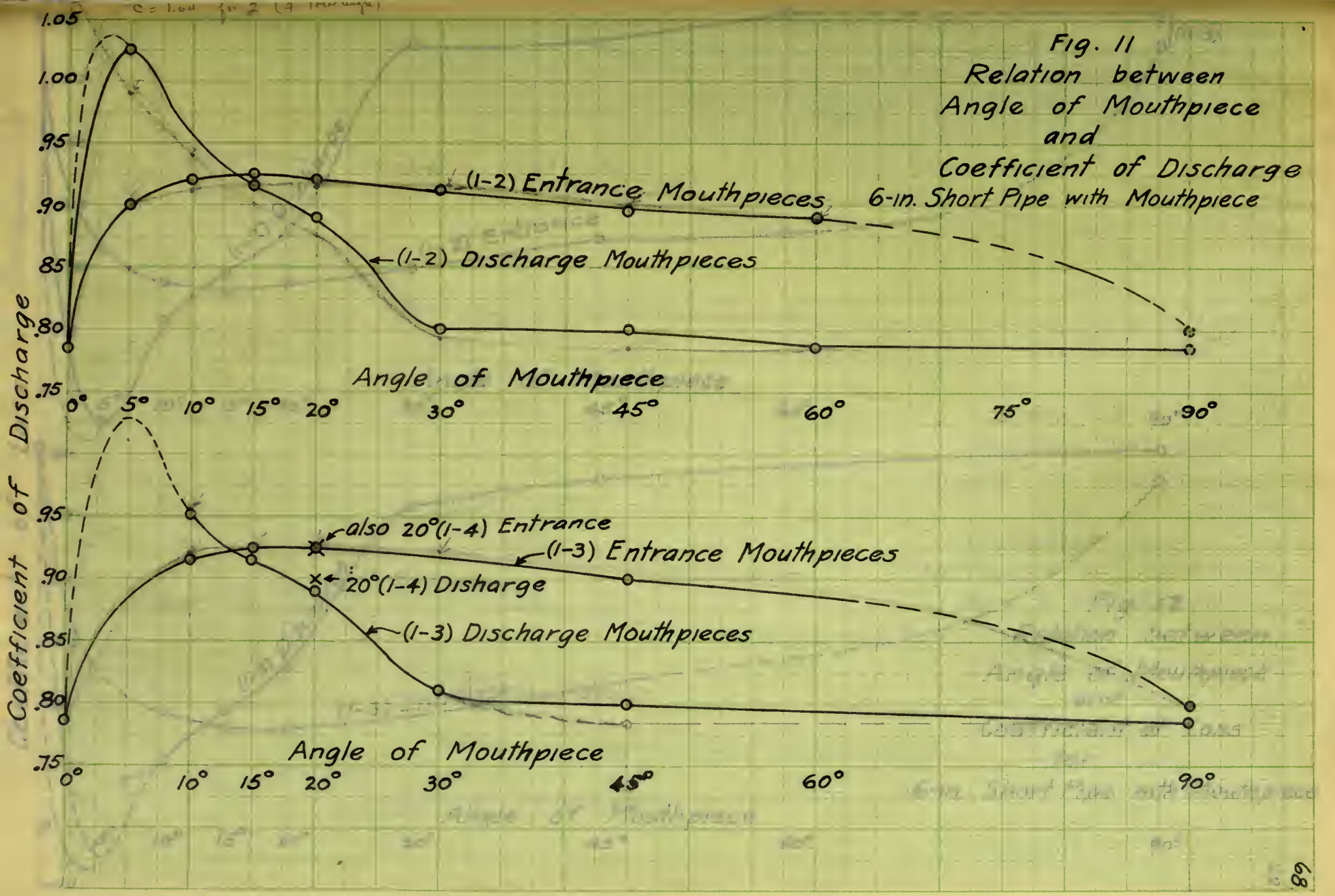
Fig. 11
Relation between
Angle of Mouthpiece
and
Coefficient of Discharge
6-in. Short Pipe with Mouthpiece
(1-2) Entrance Mouthpieces
(1-2) Discharge Mouthpieces
Coefficient of Discharge
Angle of Mouthpiece
1.05
1.00
.95
.90
.85
.80
.75
0°
5°
10°
15°
20°
30°
45°
60°
75°
90°
also 20°(1-4) Entrance
(1-3) Entrance Mouthpieces
20°(1-4) Disharge
(1-3) Discharge Mouthpieces
Angle of Mouthpiece
.95
.90
.85
.80
.75
0°
10°
15°
20°
30°
45°
60°
90°

Coefficient of Discharge
Angle between Mouthpieces
and
Coefficient of Discharge of 6-in Short Pipe with Mouthpiece
Relation between Angle of Mouthpieces
Fig. 11
Coefficient to Discharge
Angle of Mouthpieces
(1-1) Discharge through Mouthpiece
(1-2) Entrance Mouthpieces
(1-3) Discharge through Mouthpiece
(1-4) Entrance Mouthpieces
Angle of Mouthpieces

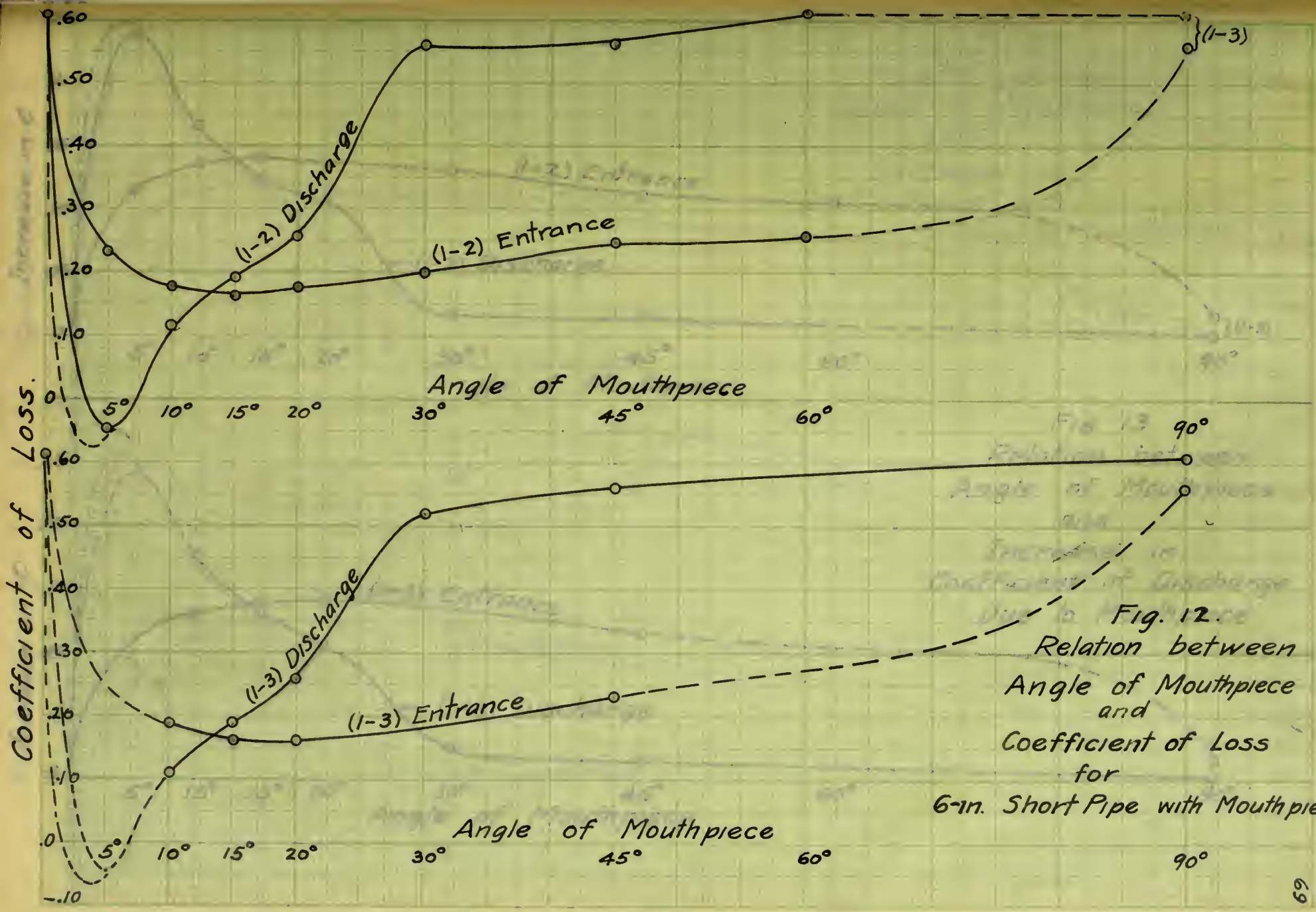

Fig. 12.
Relation between
Angle of Mouthpiece
and
Coefficient of Loss
for
6-in. Short Pipe with Mouthpiece

Coefficient of Loss

Fig. 12 Relation between Antenna and Mouthpiece for 5-in. Short Pipe with Mouthpiece

Fig. 13 Relation between Antenna and Mouthpiece for Coefficient of Loss

(1-3) Distributed

(1-3) Entrance

Antenna to Mouthpiece

(1-5) Distributed

(1-5) Entrance

Antenna to Mouthpiece

$(\varepsilon-1)$

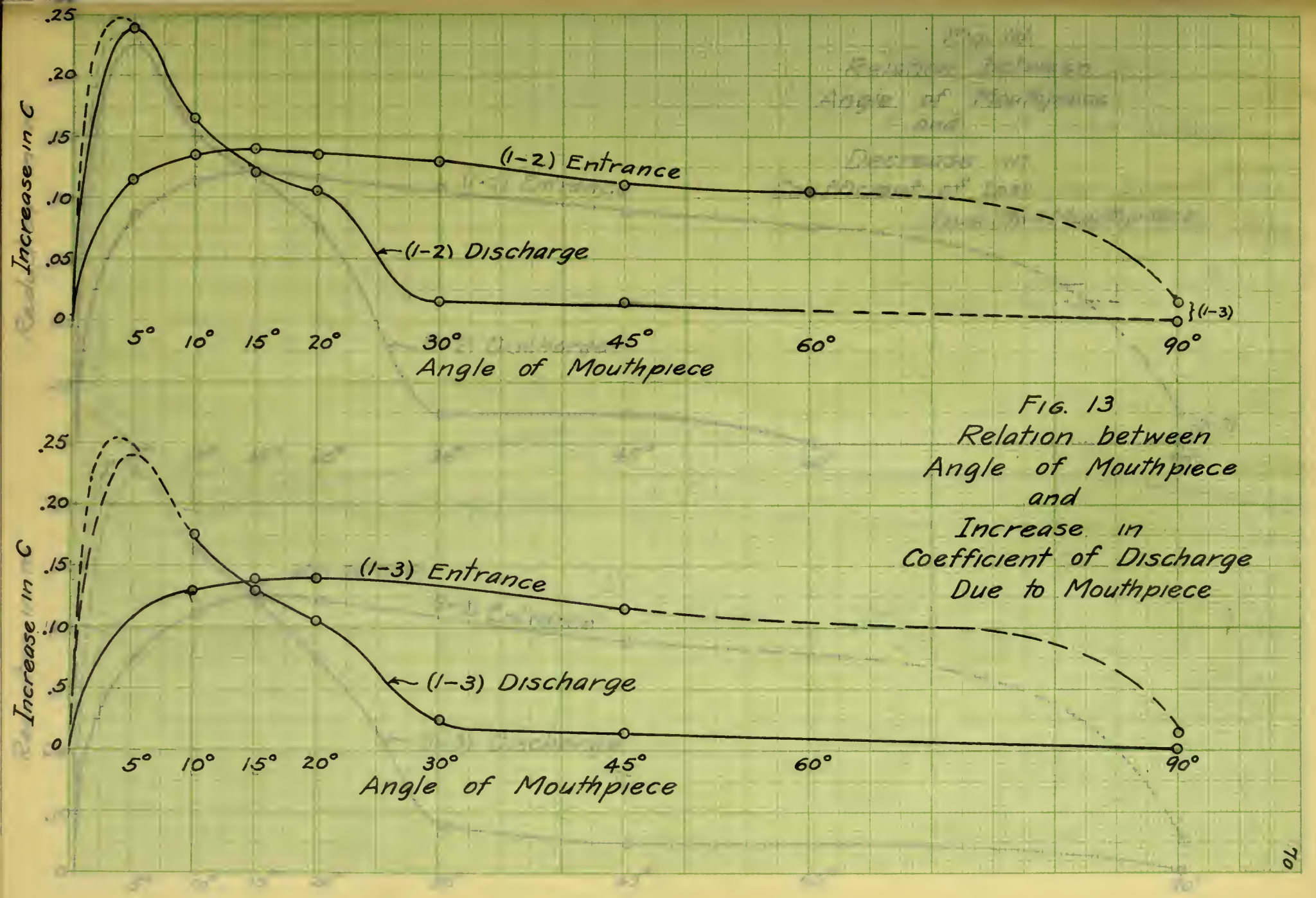

FIG. 13
Relation between
Angle of Mouthpiece
and
Increase in
Coefficient of Discharge
Due to Mouthpiece

Fig 13
Variation between Borda Mouthpiece and Re-entrant Mouthpiece
to that of the
Coefficient of Discharge
in essential

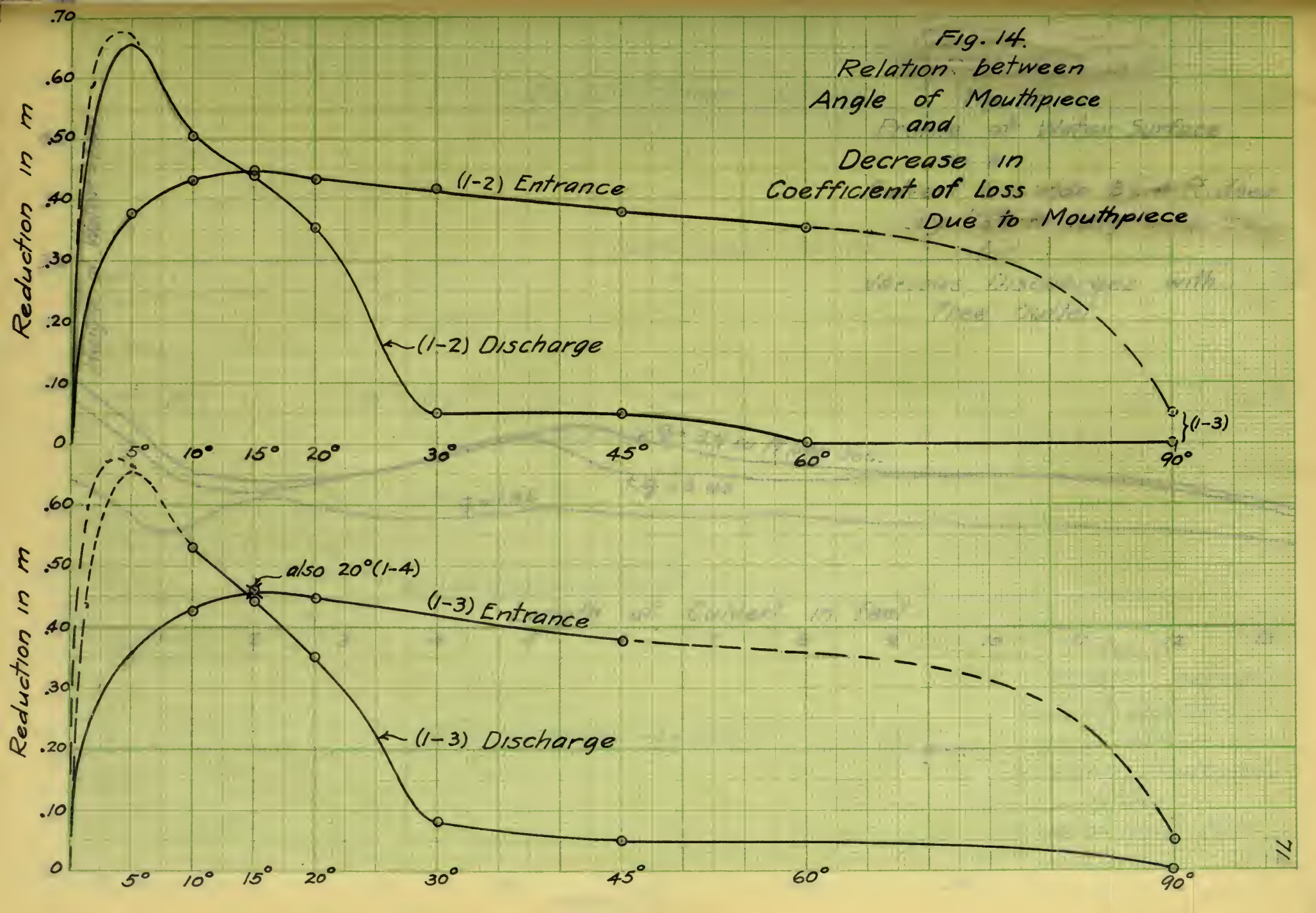
Fig. 14.
Relation between
Angle of Mouthpiece
and
Decrease in
Coefficient of Loss
Due to Mouthpiece
Reduction in m
.70
.60
.50
.40
.30
.20
.10
0
(1-2) Entrance
(1-2) Discharge
(1-3)
5°
10°
15°
20°
30°
45°
60°
90°
Reduction in m
.60
.50
.40
.30
.20
.10
0
also 20°(1-4)
(1-3) Entrance
(1-3) Discharge
5°
10°
15°
20°
30°
45°
60°
90°
71

Fig. 1.4

Relation between Maximum Velocities and Angle of Deviation in Constricted and Unconstricted Jets of Water

Velocity in m/sec

Deviation in degrees

(1-1) Unconstricted Jet

(1-2) Constricted Jet

(1-3) Orifice

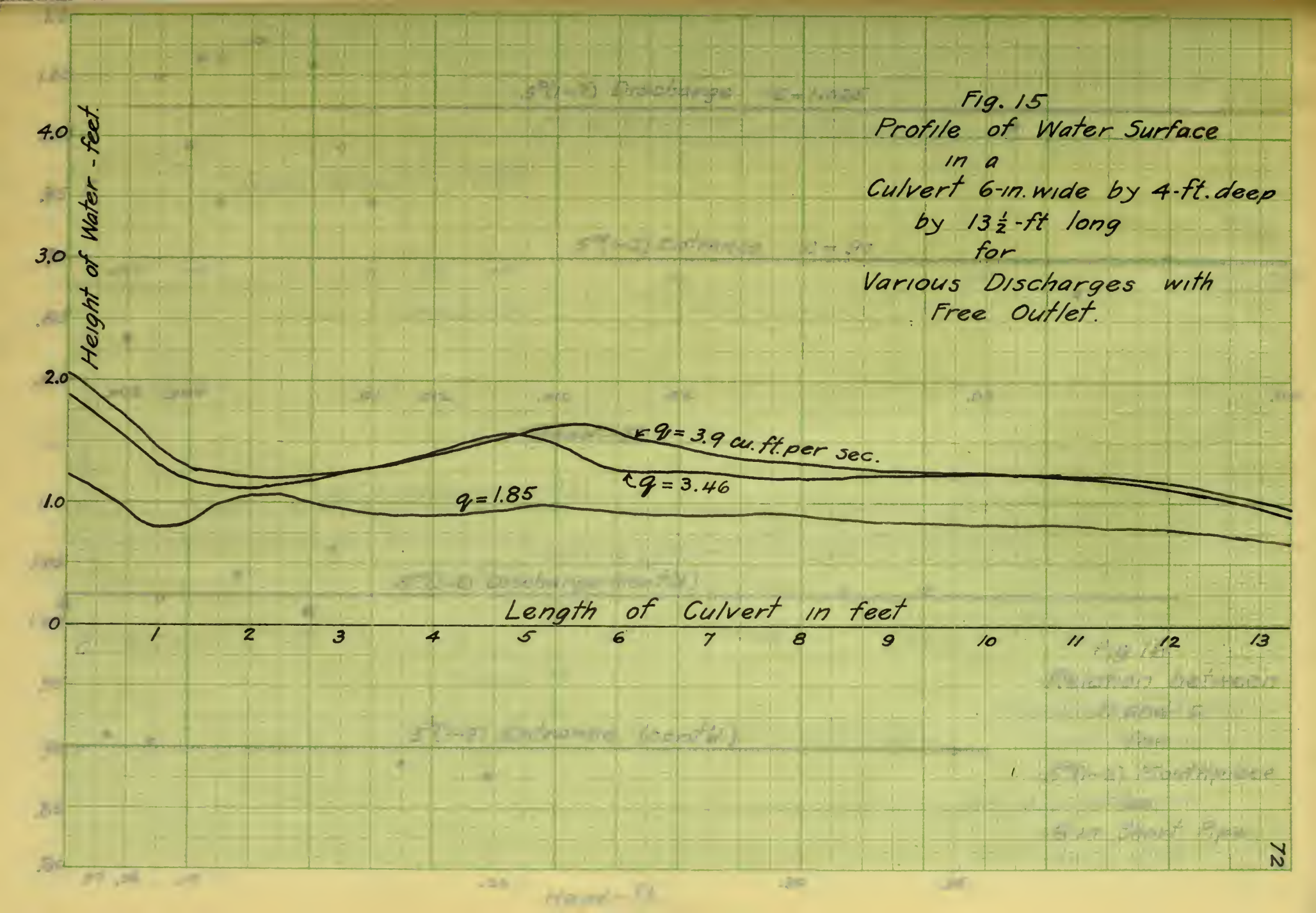

Fig. 15
Profile of Water Surface
in a
Culvert 6-in. wide by 4-ft. deep
by 13½-ft long
for
Various Discharges with
Free Outlet.

Fig. 15

Profile of Water Surface
in a
Curvent 8-in wide by 4-ft deep
by 13½-ft long
for
Various Discharges with
Free Outlet

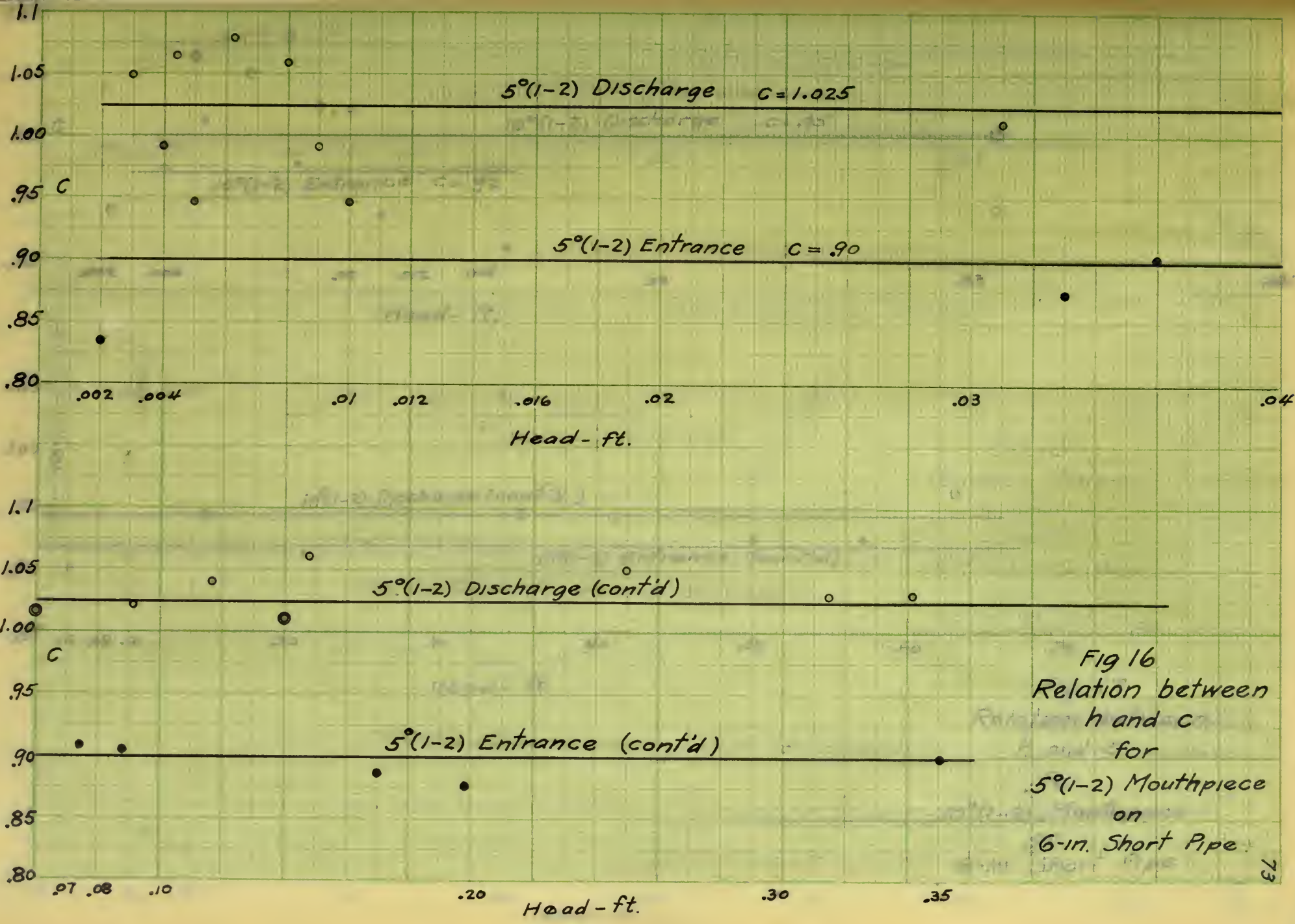

Fig 16
Relation between h and C for 5°(1-2) Mouthpiece on 6-in. Short Pipe.

Fig 18
Kissolution controlled
o and ▲
101
Mountpleasant (S-I)°C
no
Short Pipe (S-IV)
13
Discharge (S-I)°C
C=1.052
Entrance (S-I)°C
C=.98
Discharge (S-I)°C (cont'd)
Entrance (S-I)°C (cont'd)
▲ - Hooghkirk
Hooghkirk
1.1
1.05
1.0
.98
.96
.94
.92
.90
.88
.86
.84
.82
.80
.78
.76
.74
.72
.70
.68
.66
.64
.62
.60
.58
.56
.54
.52
.50
.48
.46
.44
.42
.40
.38
.36
.34
.32
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
.00

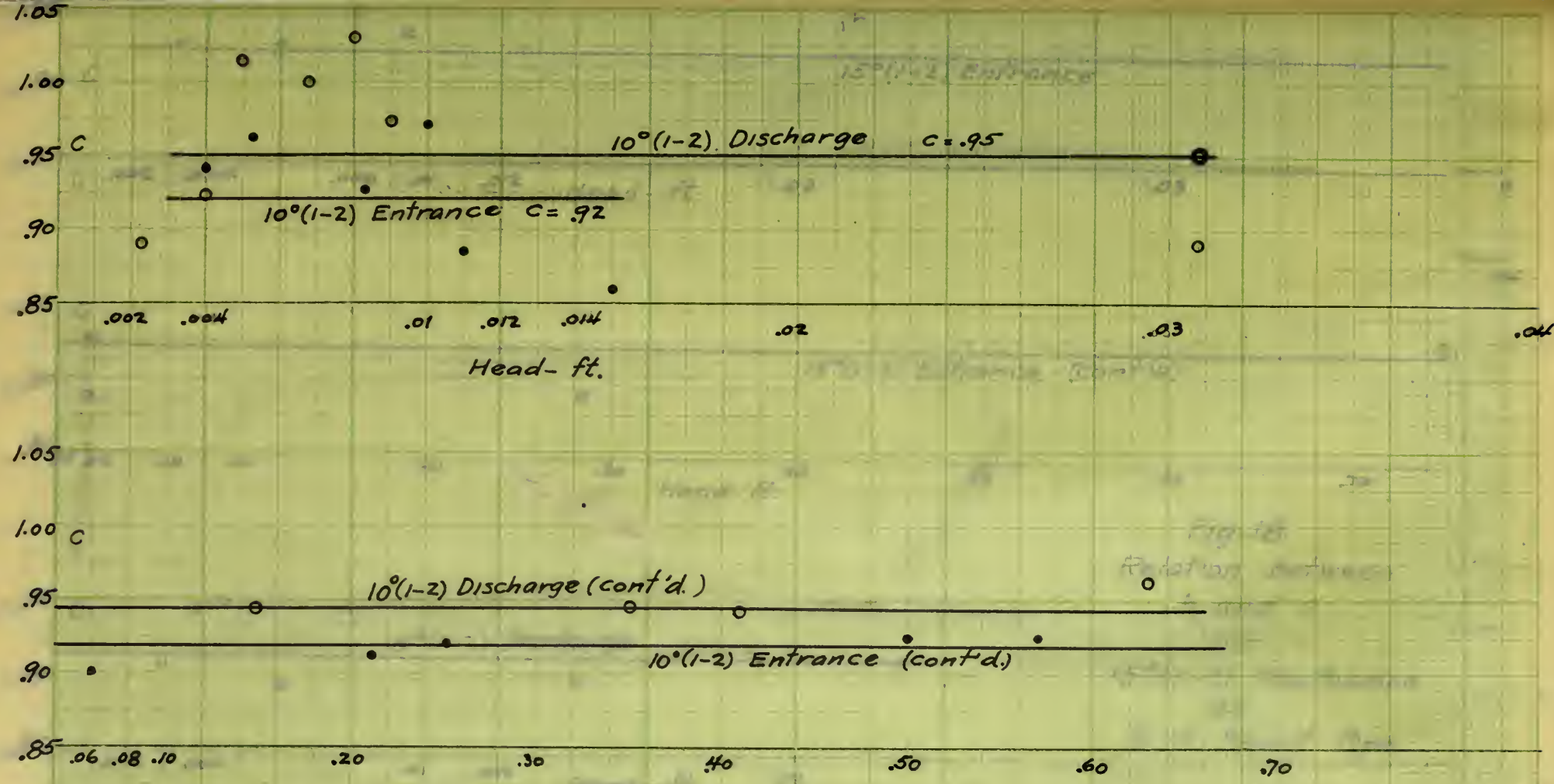

Fig. 17
Relation between
h and C
for
10°(1-2) Mouthpiece
on
6-in Short Pipe

10(1-r) Discharge (cont'd.)
10(1-r) Entrance (cont'd.)
HCOOH - kg.
10(1-r) Discharge
10(1-r) Entrance
HCOOH - kg.

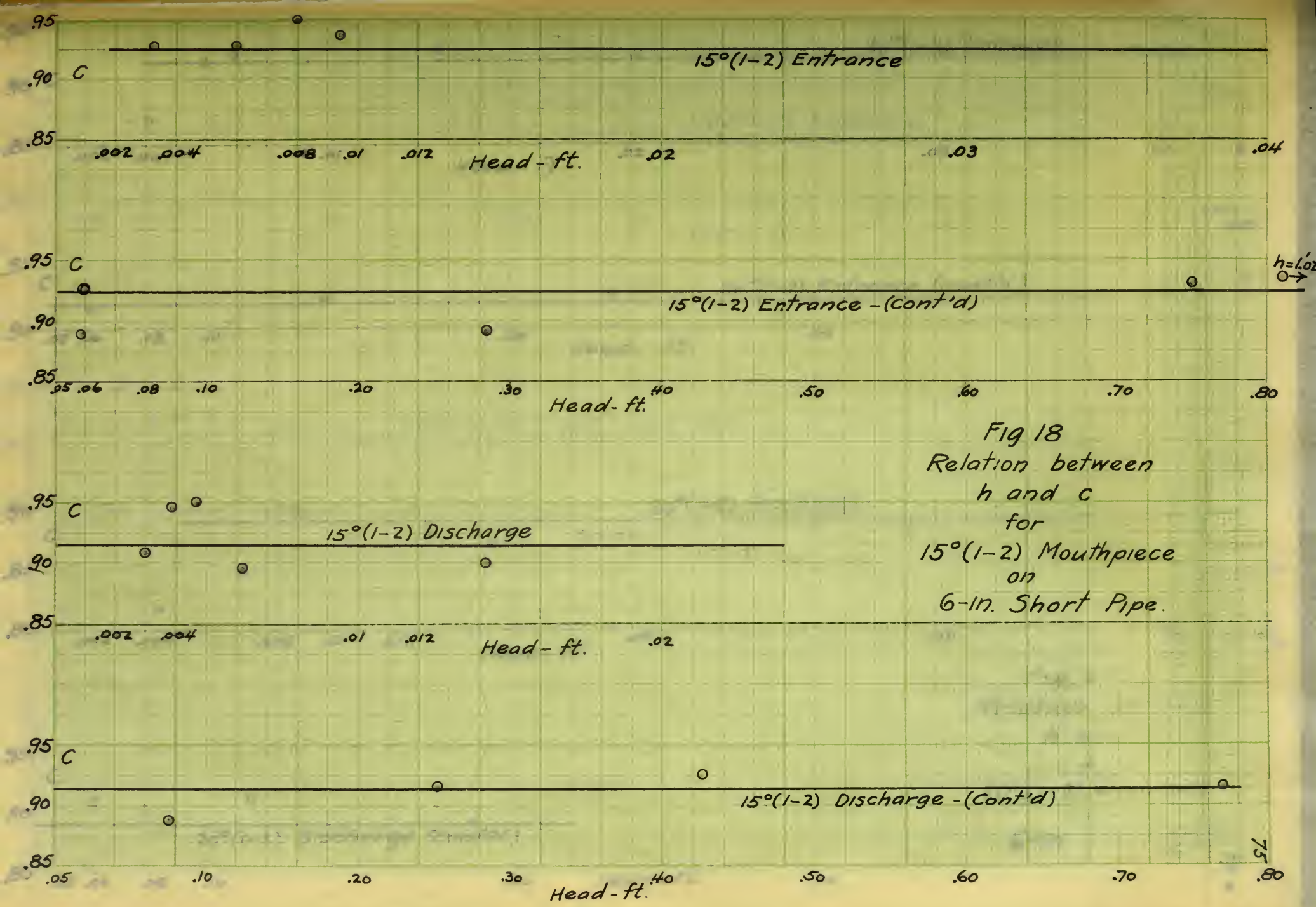

Fig 18
Relation between
h and c
for
15°(1-2) Mouthpiece
on
6-in. Short Pipe.

Fig. 18
Relation between
Load and
Deflection
for
Mo (S-1)-01
and
Mo (S-1)-02

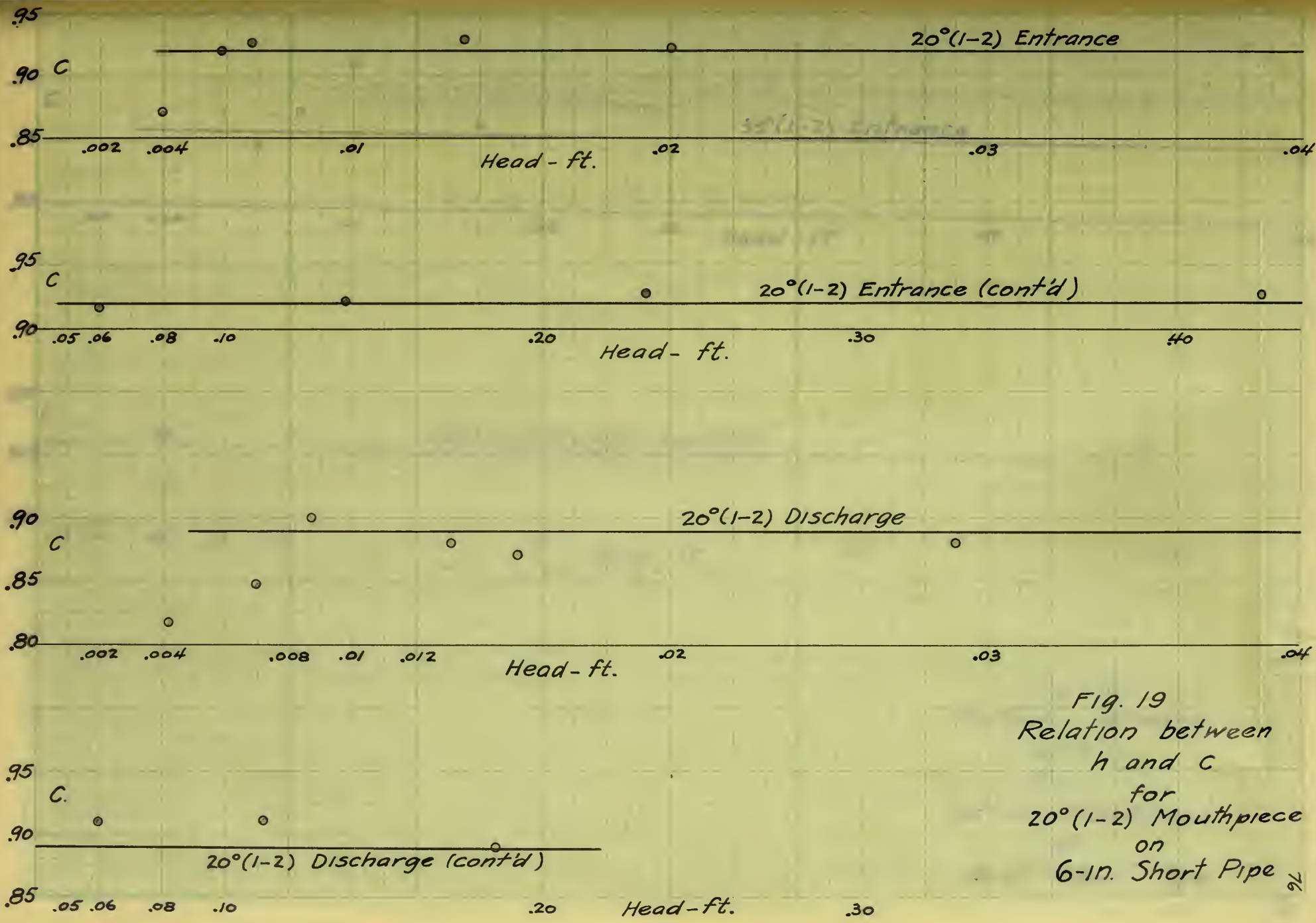

Fig. 19
Relation between
h and C
for
20°(1-2) Mouthpiece
on
6-In. Short Pipe

SO4(1-S) DISSOLVED (MG/L)
SO4(1-S) ENTRAINED (MG/L)
SO4(1-S) TOTAL (MG/L)
FIG 15
DISSOLVED SULFATE
VS
ENTRAINED SULFATE
AT
MONTICELLO (S-1) SITE
SEPT 1972 - JULY 1973
HIGH - FLOW
LOW - FLOW
HIGH - FLOW
LOW - FLOW

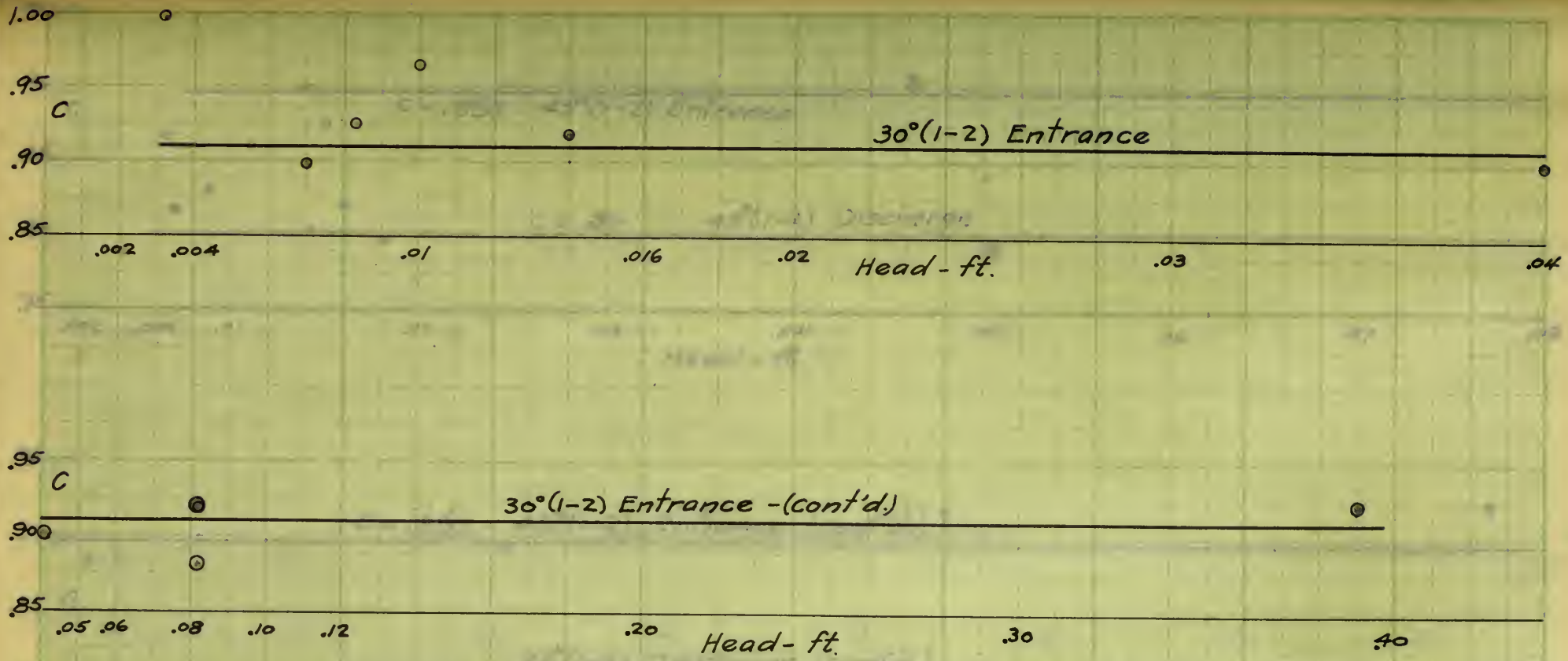

Fig. 20
Relation between
h and c
for
30°(1-2) Mouthpiece
on
6-in. Short Pipe

Fig. 25
Isothermal titration calorimetric titration of 3 mM Ca-EDTA with 30 mM Mg(NO3)2 at 25°C

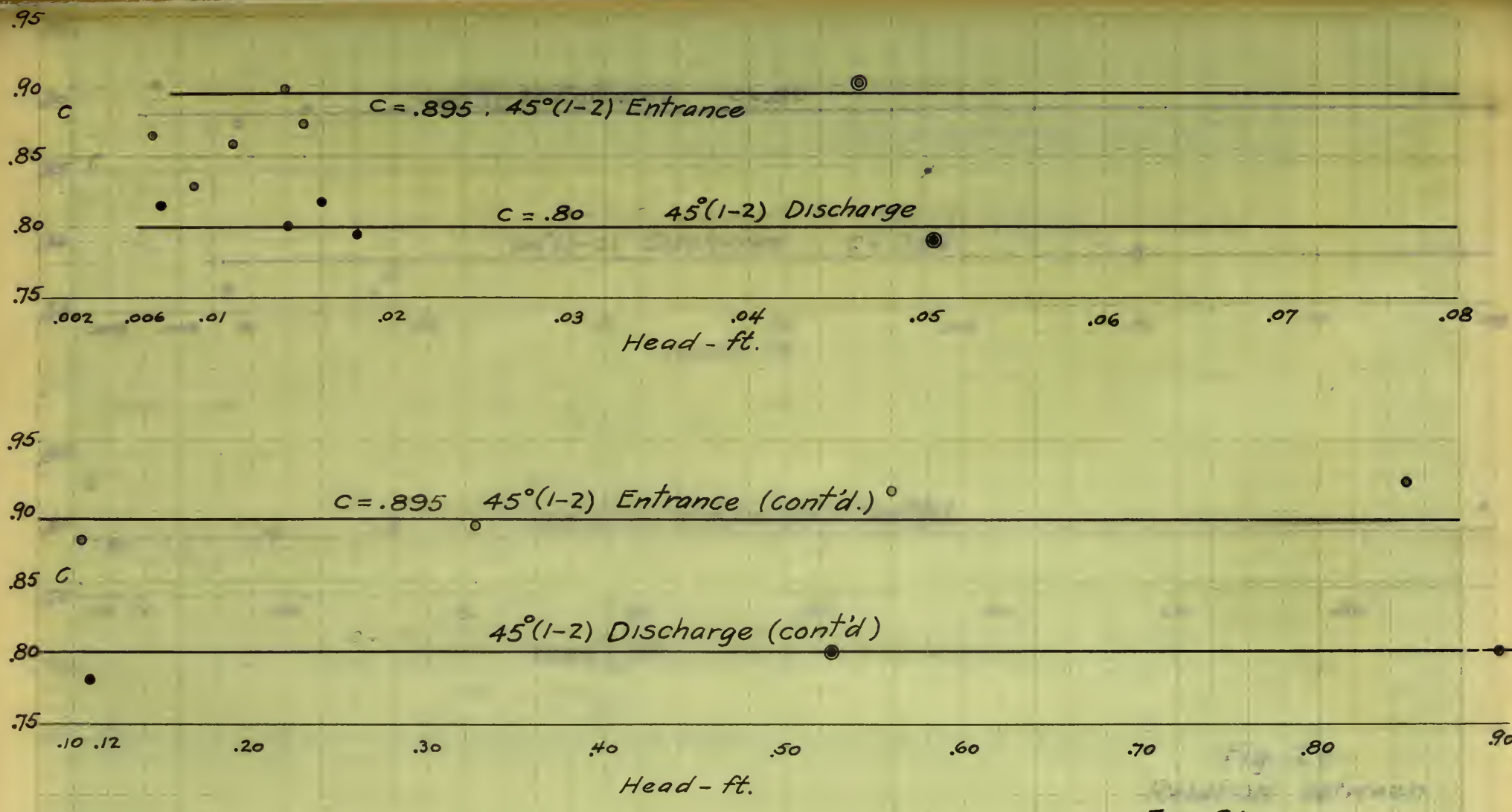

Fig 21
Relation between
h and c
for
45°(1-2) Mouthpiece on 6-in. Tube

Fig 21
Discharge curves
for 4 and 6 inch
Venturi meters

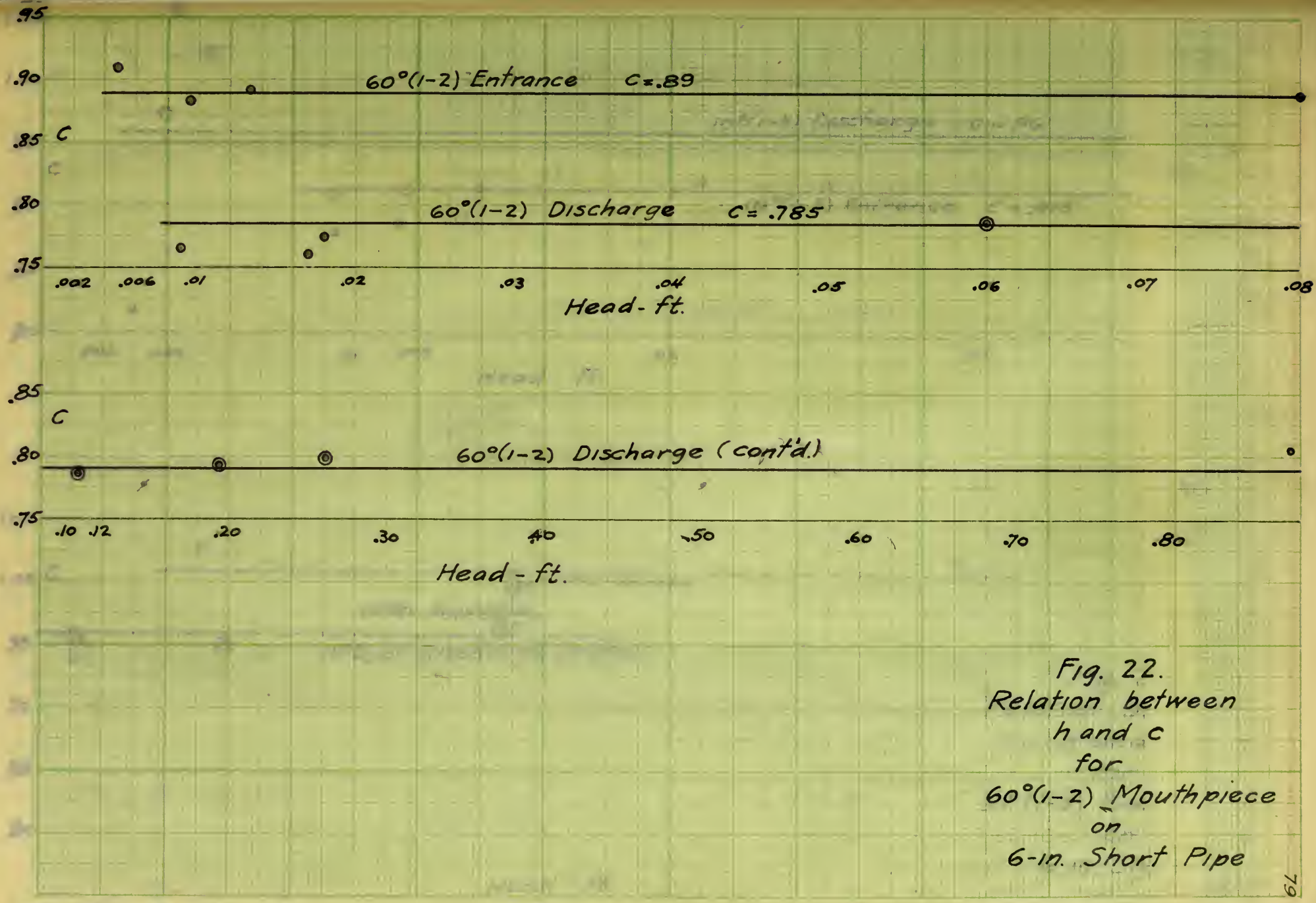

Fig. 22.
Relation between
h and C
for
60°(1-2) Mouthpiece
on
6-in. Short Pipe

Fig. 23.
Relation between
H and Q
for
90°(1-2) Triangular Notch
in Short Pipe

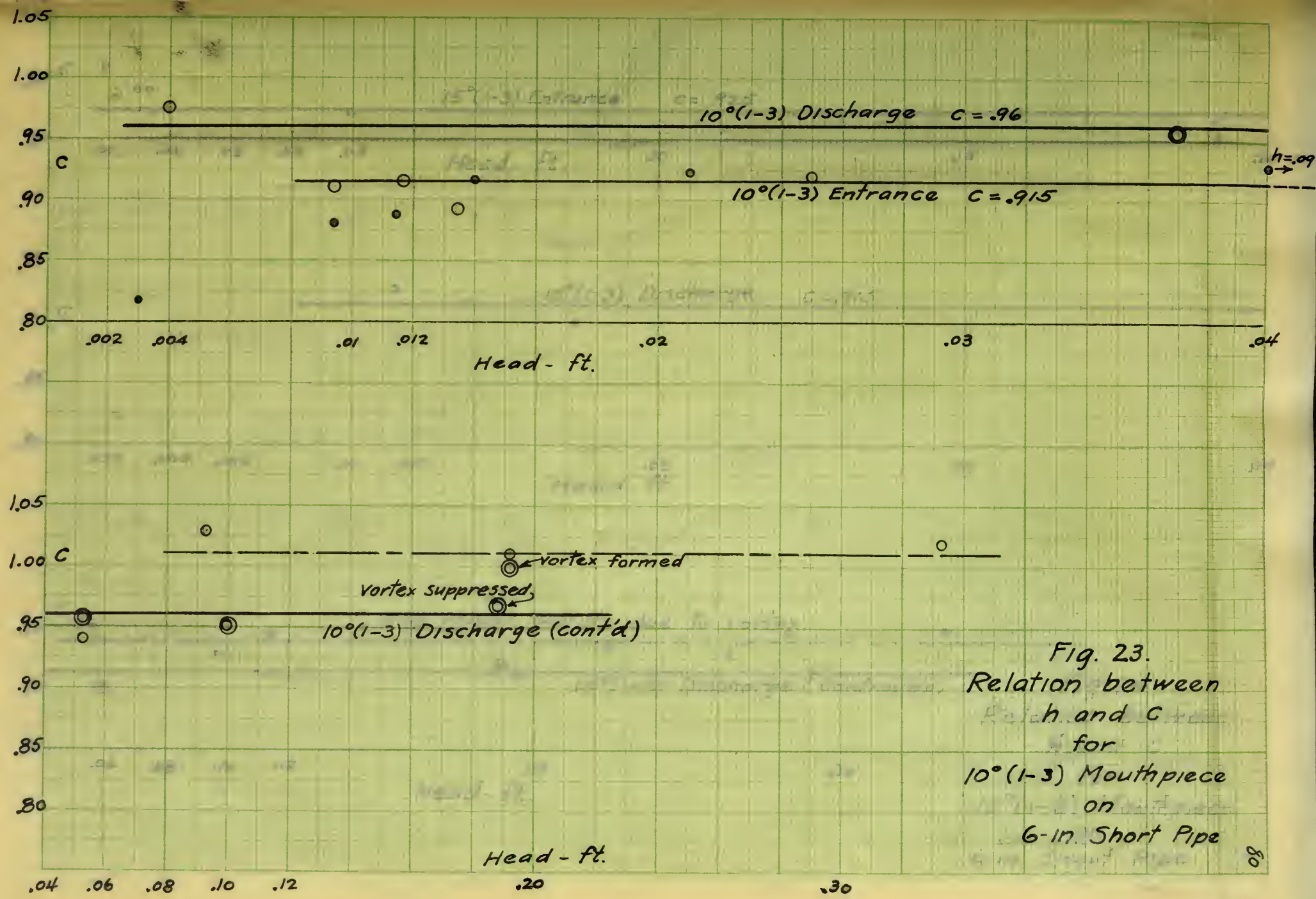

Fig. 23.
Relation between h and C for 10° (1-3) Mouthpiece on 6-in. Short Pipe

Fig. 23
Oxidation Potential
0 hrs
48 hrs
10^(-1) Monohydrate
10^(-2)
10^(-3) Dihydrate
Hash -

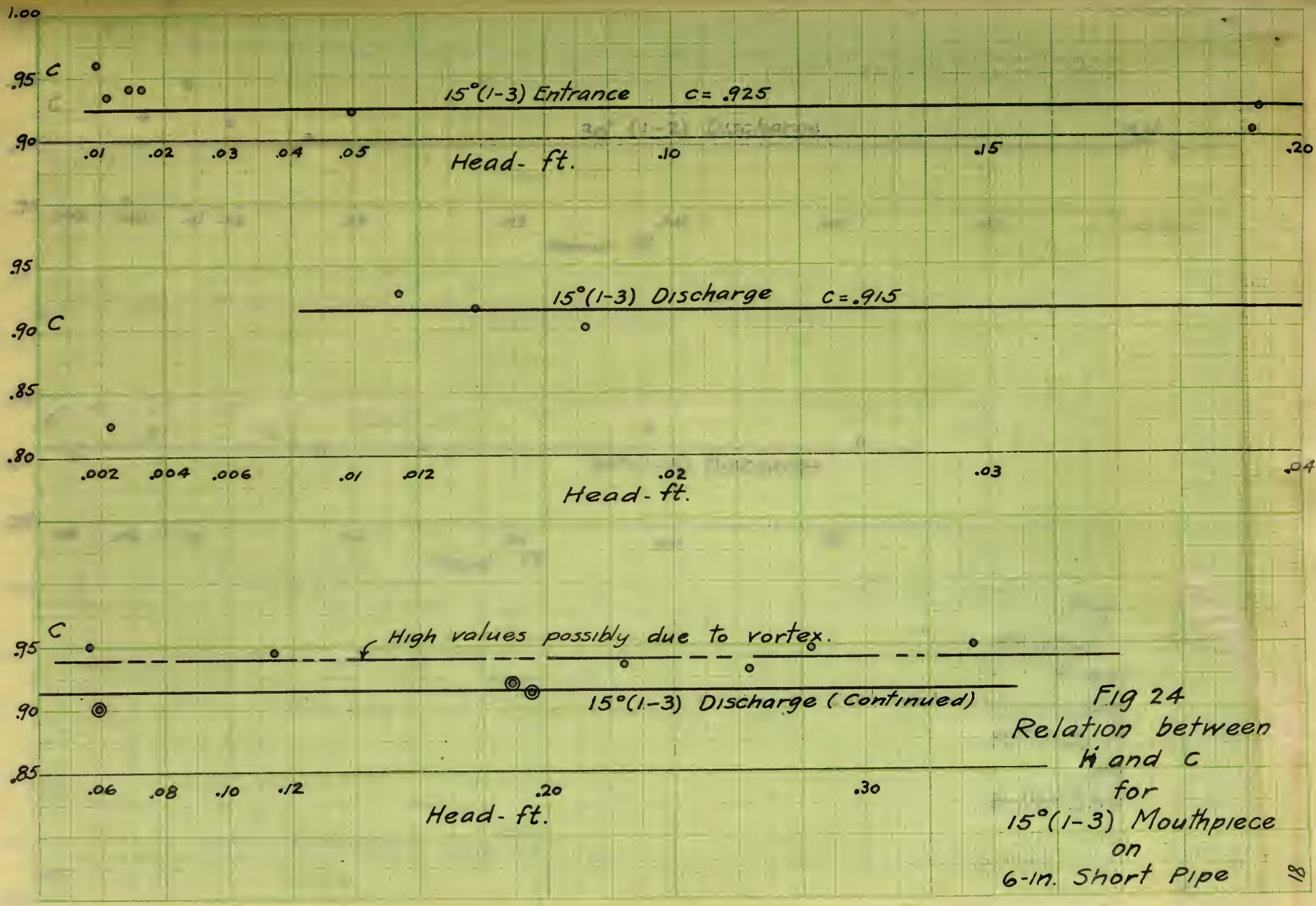

Fig 24
Relation between H and C for 15°(1-3) Mouthpiece on 6-in. Short Pipe

Head - ft.
Discharge (Q) - cfs
Head - ft.
Discharge (Q) - cfs
Head - ft.
Discharge (Q) - cfs

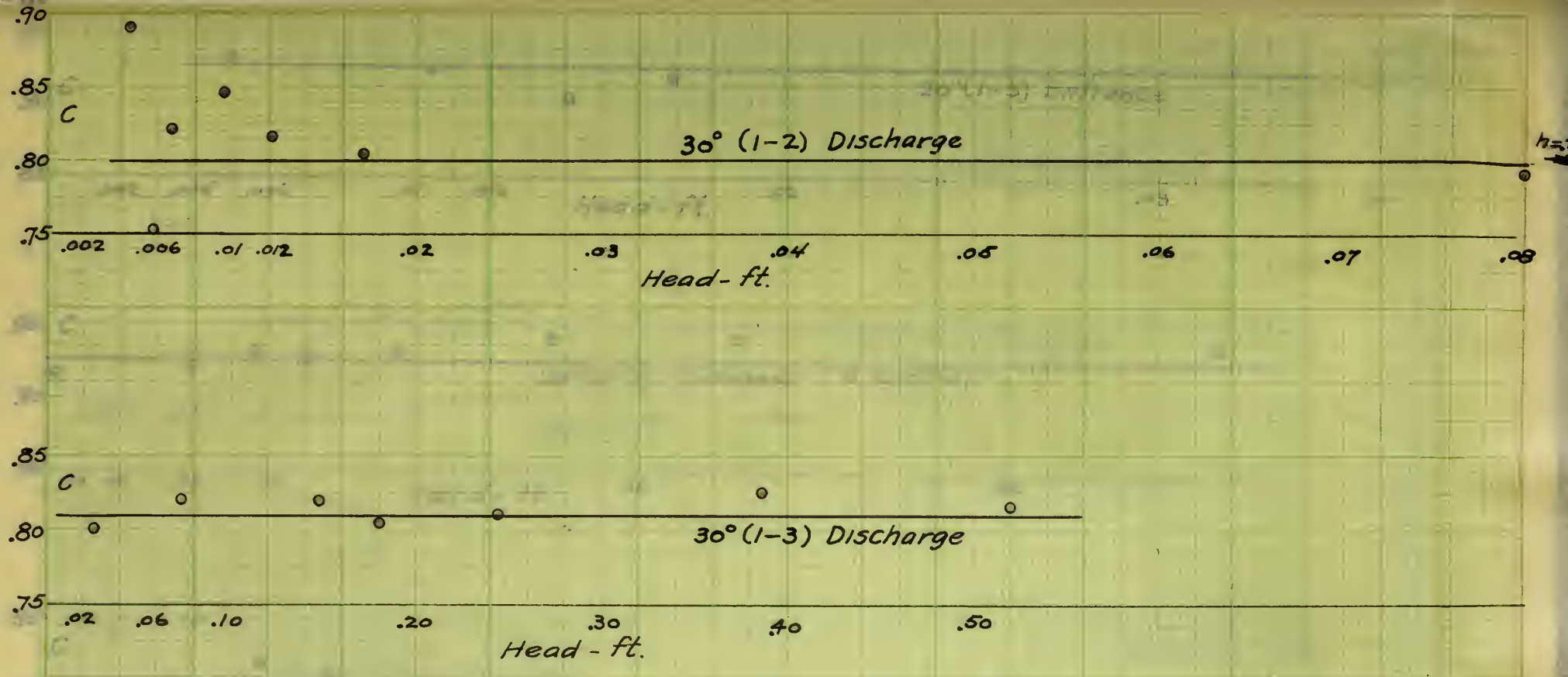

Fig. 25
Relation between
h and c
for
30° (1-3) Mouthpiece
on
6-In. Short Pipe

Fig. 25

Relation between
Q and H
for
30°(1-3) Mouthpiece
on
6-in Short Pipe

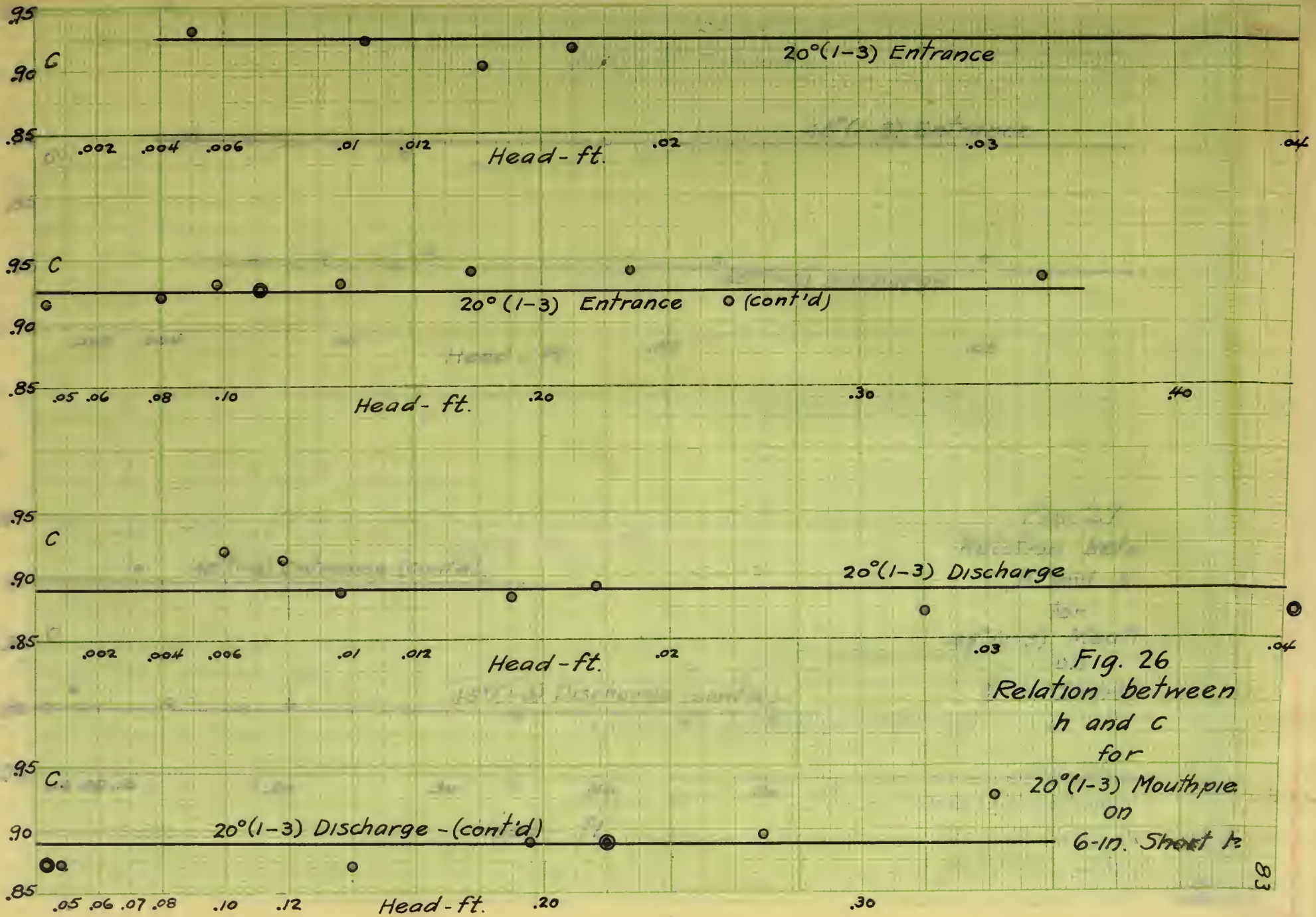

Fig. 26
Relation between
h and C
for
20°(1-3) Mouthpie
on
6-in. Short h

Fig. 22
Relative position of C band in
Sm(III) Emission
Sm(III) Emission (contd)
Sm(III) Excitation
Sm(III) Excitation (contd)
Wavelength (Å)
Wavelength (Å)
Wavelength (Å)
Wavelength (Å)

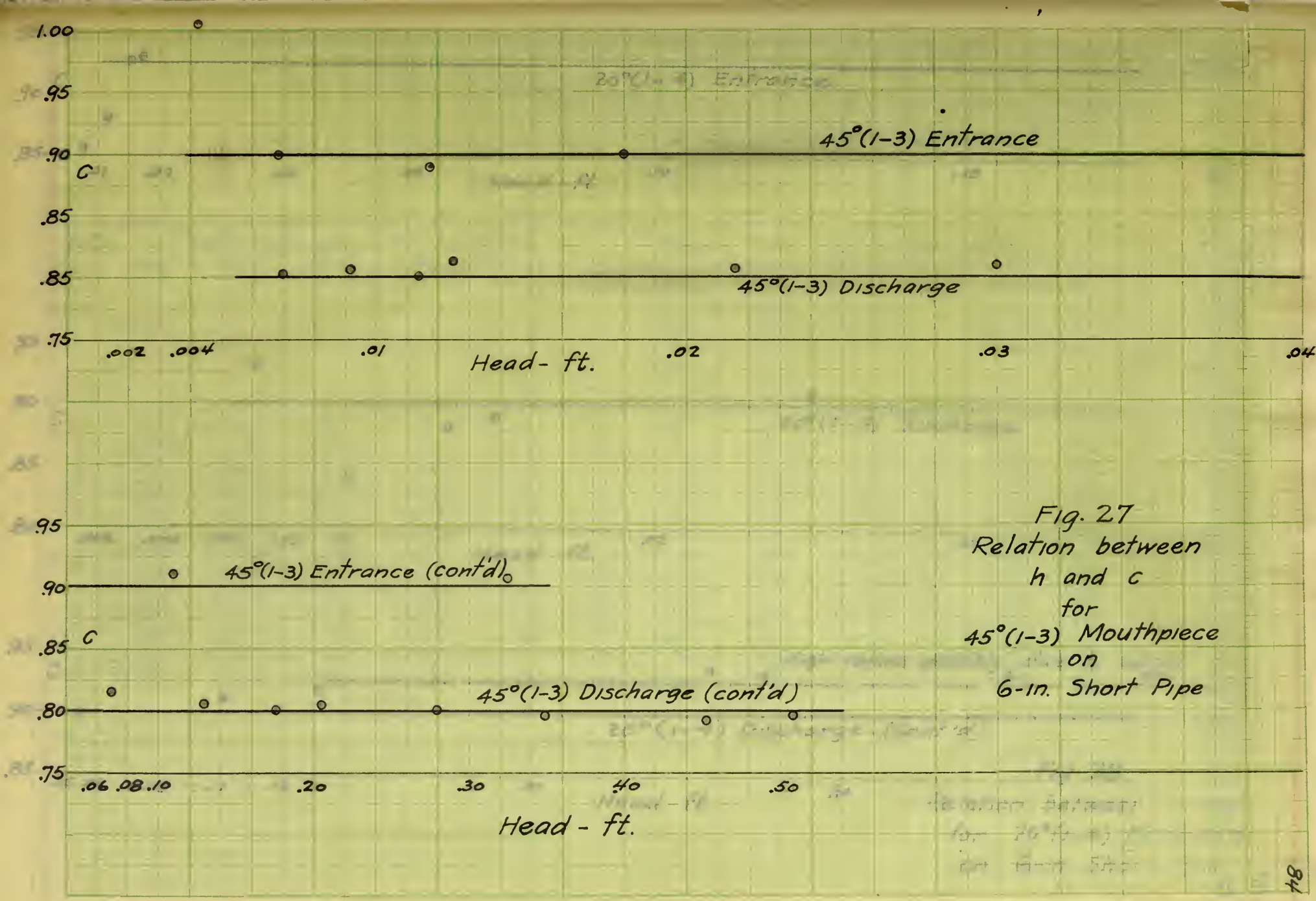

Fig. 27
Relation between
h and c
for
45°(1-3) Mouthpiece
on
6-in. Short Pipe

Fig. 21
Relation between
Mountain Pine
and
Mountainous
Ft - Head
Ft - Head
Discharge (cusecs)
Discharge (cusecs)
Efficiency (%)
Efficiency (%)

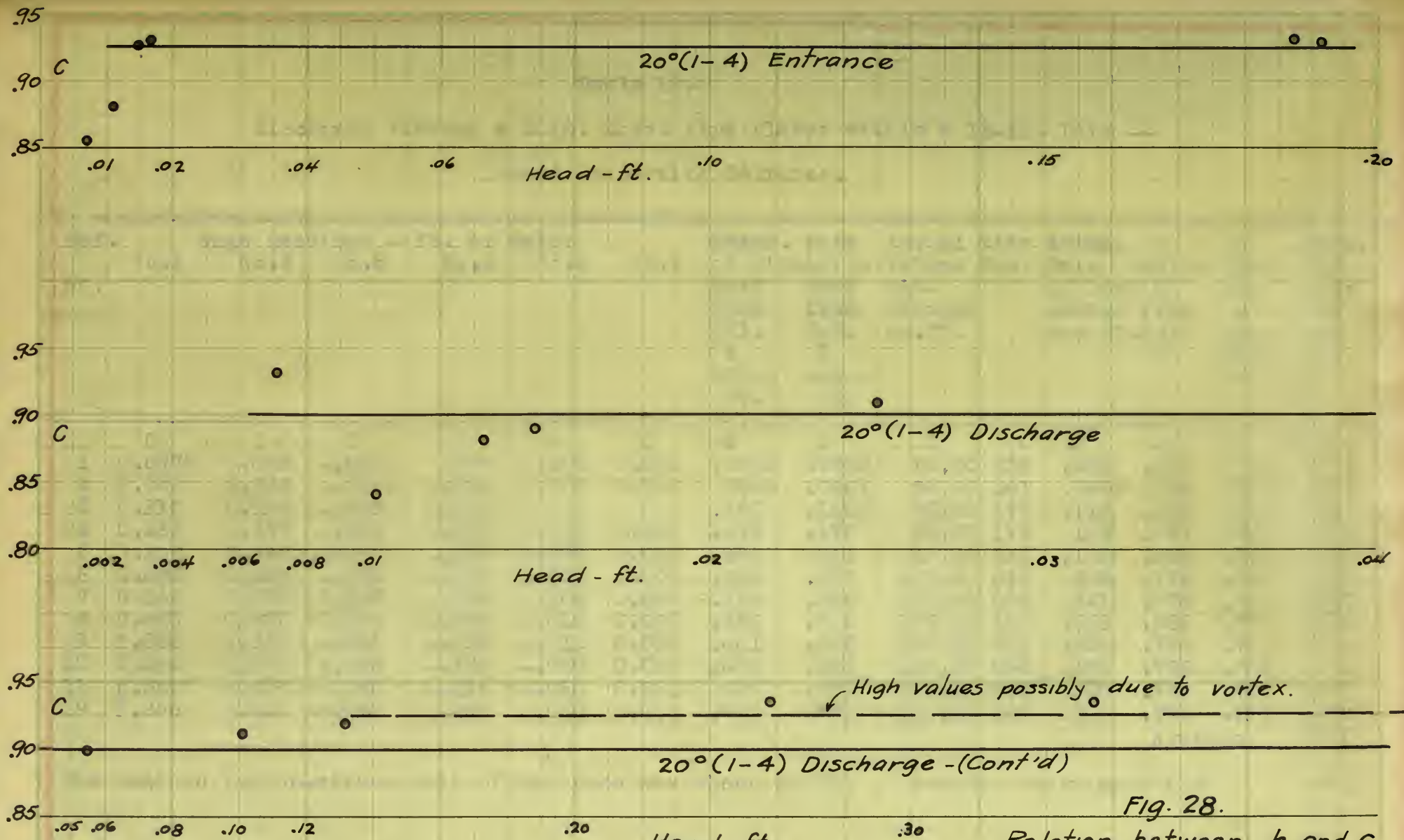

Fig. 28.

Relation between h and C for 20°(1-4) Mouthpiece on 6-in. Short Pipe.

Fig. 58.
Hood - 47.
Hood - 47.
Hood - 47

Table 14.

Discharge through a 3-in. Short Pipe Places within a 12-in. Pipe —

Inward Projecting Entrance.

Ref. No.	Gage Readings — ft. of Water No.1	No.2	No.3	No.4	No.5	No.6	Theor. Rate of Discharge Head from Col. 2 sec.-ft.	Head from Col. 3 sec.-ft.	Actual Volume Discharged cu.ft.	Time Sec.	Actual Rate of Discharge sec.ft.	c Taking Q from Col. 8	c Taking Q from Col. 9	Aver. of Cols. 13 and 14
	0	0	0	0	0	0	Q	0	0	0	0	0	0	0
1	0.0175	0.023	-.005	.002	-.001	0.000	.0559	.0598	10.00	222	.045	.805	.752	.778
2	0.038	0.042	-.0045	0.000	0.000	0.000	.0824	.0867	25.00	381	.0656	.796	.757	.776
3	0.110	0.124	-.003	-.003			.140	.1488	20.00	177	.113	.808	.760	.784
4	0.163	0.177	-.003	-.010	-.002	0.000	.170	.178	25.00	179	.139	.781	.782	.782
5	0.229	0.248	-.003	-.015	-.002	0.000	.202	.211	25.00	154	.162	.803	.768	.785
6	0.393	0.430	-.004	-.025	-.004	-.001	.265	.277	135.5	660	.205	.775	.740	.758
7	0.545	0.595	0.000	-.039	-.004	-.003	.312	.326	115.76	480	.241	.774	.740	.757
8	0.825	0.905	0.000	-.060	-.015	0.000	.384	.402	129.80	420	.309	.805	.770	.788
9	1.090	1.200	-.004	-.085	-.015	0.000	.441	.463	126.75	360	.352	.797	.761	.784
10	1.580	1.770	+.015	-.130	-.020	0.000	.532	.563	127.00	300	.424	.796	.753	.775
11	2.510	2.800	+.020	-.210	-.050	0.000	.670	.707	127.15	240	.530	.792	.750	.771
12	3.235	3.540	+.020	-.240	-.060	0.000	.760	.796	180.25	300	.600	.790	.754	.772
												Average		.776

The head on the up-stream side of the tube was about 23 ft. Average omitting 6 & 7 .780

Table 15.

Discharge through a 3-in. Short Pipe Placed within a 12-in. Pipe — Inward Projecting Entrance.

Ref. No.	Gage Readings — ft. of Water. No.1	No.2	No.3	No.4	No.5	No.6	Theor. Rate of Discharge Head from Col. 2 sec.-ft.	Head from Col. 3 sec.-ft.	Actual Volume Discharged cu.ft.	Time sec.	Actual Rate of Discharge sec.ft.	c Taking Q from Col. 8	c Taking Q from Col. 9	Aver. of Cols. 13 and 14
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.105	0.115	0.000	-.005	0.000	-.003	0.137	0.1434	24.00	214	.112	.818	.782	.800
2	0.250	0.272	0.004	-.020	0.000	0.000	0.211	0.220	25.00	144	.173	.820	.786	.803
3	0.390	0.420	0.000	-.025	-.003	-.002	0.264	0.274	25.00	118	.212	.803	.774	.788
4	0.590	0.638	0.005	-.045	-.006	0.000	0.325	0.3375	131.20	510	.258	.795	.766	.781
5	0.835	0.905	-.005	-.060	-.010	0.000	0.386	0.403	118.51	451	.263	.783	.652	.718
6	0.985	1.078	0.000	-.070	-.020	0.000	0.420	0.438	121.30	300	.404	.952	.922	.937
7	1.480	1.605	-.010	-.100	-.025	0.000	0.514	0.536	122.32	300	.407	.793	.760	.777
8	2.015	2.16	+.005	-.113	-.025	0.003	0.600	0.621	142.32	300	.473	.789	.762	.776
9	3.13	3.44	+.015	-.250	-.050	0.003	0.748	0.784	155.10	260	.596	.797	.762	.780
10	4.32	4.69	0.020	-.330	-.075	0.000	0.880	0.915	205.25	290	.706	.700	.772	.786
11	5.30	5.69	0.025	-.360	-.090	0.000	0.973	1.004	183.00	240	.763	.785	.759	.772
12	7.04	7.56	0.025	-.53	-.120	0.000	1.120	1.162	214.07	242	.885	.790	.762	.776
													Average	.790

The head on the up-stream side was about 50 ft. Average omitting 6 & 7 .784

Table 16.

Discharge through a 3-in. Short Pipe Placed within a 12-in. Pipe — Inward Projecting Entrance.

Ref. No.	Gage Readings — ft. of Water. No.1	No.2	No.3	No.4	No.5	No.6	Theor. Rate of Discharge Head from Col. 2 sec.-ft.	Head from Col. 3 sec.-ft.	Actual Volume Discharged cu.ft.	Time sec.	Actual Rate of Discharge sec.ft.	c Taking Q from Col. 8	c Taking Q from Col. 9	Aver. of Cols. 13 and 14
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.011	0.015	-.005	+.003	-.005	0.000	0.0444	0.0517	10.00	249	0.0401	.904	.775	.840
2	0.051	0.062	-.005	-.003	-.004	0.000	0.0954	0.105	20.00	245	0.0816	.856	.777	.816
3	0.093	0.107	-.005	-.006	-.004	0.000	0.1288	0.138	25.00	233	0.1071	.833	.777	.805
4	0.150	0.164	-.005	-.004	-.005	0.000	0.164	0.171	25.00	189	0.132	.805	.773	.789
5	0.234	0.250	-.003	-.012	-.003	0.000	0.204	0.211	25.00	151	0.136	.815	.787	.801
6	0.388	0.430	-.002	-.027	-.007	0.000	0.264	0.277	25.00	117	0.214	.811	.773	.792
7	0.60	0.665	0.000	-.040	-.02	0.000	0.328	0.345	25.00					
8	0.845	0.925	-.02	-.06	-.012	0.000	0.388	0.406	120.90	390	0.310	.799	.763	.781
9	1.14	1.225	-.022	-.085	-.017	0.000	0.452	0.468	117.85	330	0.356	.789	.760	.775
10	1.61	1.715	-.025	-.115	-.025	0.000	0.536	0.554	110.75	270	0.410	.755	.740	.748
11	2.54	2.76	-.015	-.19	-.03	0.000	0.675	0.704	91.4	170	0.537	.796	.754	.775
12	3.85	4.17	-.01	-.26	-.06	0.000	0.830	0.918	125.20	181	0.693	.834	.755	.795
13	6.27	6.80	+.03	-.45	-.09	0.000	1.060	1.105	125.90	150	0.840	.792	.760	.776
14	8.10	8.65	+.04	-.55	-.12	0.000	1.20	1.24	142.90	150	0.953	.794	.768	.781
15	10.85	11.78	+.04	-.88	-.23	0.000	1.45	1.485	170.90	150	1.140	.788	.768	.778
16	12.85	13.95	+.05	-.97	-.21	-.01	1.515	1.580	186.00	157	1.185	.784	.750	.767
													Average	.788
													Average omitting 10	.790

The head on the up-stream side varied from 41 ft. to 50 ft.

Table 17.

Experimental Data with Submerged Orifices having Sharp Edges.

Submergence –

Ref. No.	Head h_3-h_1 ft. h	Time Sec. t	Rise in Pit ft. p	Discharge Actual cu.ft. per sec. q	Discharge Theoretical cu. ft.per sec. Q	Actual Av.Velocity ft.per sec. v	Coefficient of Discharge c	Coefficient of Loss m	Remarks
1	2	3	4	5	6	7	8	9	11
				4–in. Round Orifice – Submerged.					
1	0.0265	880	1.205	0.0685	0.115	0.776	0.596	1.81	
2	0.0264	920	1.285	0.070	0.115	0.789	0.608	1.70	
3	0.0264	990	1.360	0.068	0.115	0.776	0.595	1.80	
4	0.063	622	1.332	0.107	0.177	1.21	0.604	1.74	
5	0.063+	615	1.316	0.107	0.177	1.21	0.604	1.74	
6	0.061	645	1.347	0.1046	0.175–	1.18	0.598	1.79	
7	0.062–	675	1.420	0.105+	0.176	1.19	0.595	1.82	
				4–in. x 4–in. Square Orifice.					
8	0.056	725	1.840	0.127	0.2105	1.14	0.604	1.74	
9	0.0565	735	1.863	0.1268	0.211–	1.14	0.602	1.75	
10	0.057	650	1.658	0.1278	0.2125	1.15	0.602	1.75	
11	0.057–	650	1.672	0.1288	0.2120	1.16	0.607	1.71	
12	0.0363	720		0.0943	0.1695	0.850			
13	0.0352	866	1.741	0.1005	0.1669	0.905	0.603	1.75	
14	0.036–	660	1.316	0.0999	0.1688	0.900	0.592	1.85	
15	0.0365	571	1.151	0.1009	0.1695	0.910	0.596	1.81	

1	2	3	4	5	6	7	8	9	10
				$5\frac{1}{2}$ – in. x $5\frac{1}{2}$ – in. Square Orifice – Submerged.					
16	0.0382	500	1.937	0.1940	0.329	0.923	0.590	1.87	
17	0.0385	524	2.065	0.1978	0.330	0.940	0.599	1.78	
18	0.038	506	1.988	0.1965	0.329	0.935	0.597	1.80	
19	0.0385	480	1.899	0.1978	0.330	0.940	0.599	1.78	
20	0.049	416	1.872	0.225	0.373	1.07	0.604	1.74	
21	0.048	416	1.862	0.224	0.369	1.06	0.607	1.71	
22	0.1075	284	1.908	0.336	0.551	1.59	0.610	1.68	
23	0.1085	312	2.097	0.336	0.555	1.59	0.606	1.72	
24	0.109–	280	1.092	0.340	0,556	1.61	0.612	1.67	
				1/2–in. x 6–in. Rectangular Orifice.					
25	0.317	910	1.082	0.0596	0.0939	2.88	0.635	1.47	
26	0.311	979	1.155	0.0591	0.0930	2.86	0.635	1.47	
27	0.636	605	1.012	0.0840	0.133	4.07	0.632	1.50	
28	0.622	728	1.200	0.0826	0.1318	4.00	0.628	1.53	
29	0.613	743	1.232	0.0832	0.1307	4.02	0.637	1.46	
30	0.9855	679	1.424	0.105	0.1654	5.09	0.635	1.47	
31	0.999	674	1.416	0.1053	0.1667	5.09	0.633	1.50	
				1–in. x 6–in. Rectangular Orifice.					
32	0.024	1145	0.750	0.0328	0.0516	0.785	0.636	1.47	
33	0.024	1260	0.820	0.0326	0.0516	0.785	0.636	1.47	
34	0.1223	655	0.966	0.0739	0.1165	1.76	0.634	1.48	
35	0.1220	750	1.108	0.0740	0.1163	1.76	0.636	1.47	
36	0.1210	630	0.913	0.0727	0.1160	1.74	0.627	1.54	
37	0.1205	630	0.921	0.0732	0.1160–	1.75	0.631	1.52	
38	0.1350	740	1.140	0.077	0.1225	1.84	0.629	1.52	

1	2	3	4	5	6	7	8	9	10
39	0.1918	675	1.239	0.0920	0.1457	2.19	0.632		
40	0.1930	640	1.177	0.0920	0.1462	2.19	0.629		
41	0.195	620	1.148	0.0927	0.1472	2.20	0.629		
42	0.3495	695	1.724	0.1244	0.1974	2.96	0.632		
43	0.351	695	1.702	0.1225	0.1975	2.91	0.623		
44	0.326	600	1.427	0.1190	0.1904	2.84	0.625		
45	0.119	975	1.403	0.0722	0.1150	1.72	0.628		
46	0.117	963	1.364	0.0710	0.1140	1.69	0.623		
47	0.1185	891	1.283	0.0721	0.1146	1.72	0.629		
48	0.116	600	0.8585	0.0716	0.1133	1.70	0.632		
49	0.347	623	1.506	0.1212	0.1960	2.88	0.618		
50	0.344	600	1.459	0.1217	0.1951	2.90	0.623		
51	0.343	585	1.416	0.1218	0.1950	2.90	0.624		

Table 18.

Experimental Data with 6-in. and 2-in. Short Pipe with Entrance Flush.

Ref. No.	Head ft. $h_g - h_1$ h	Time sec. t	Rise in Pit. ft. p	Discharge Actual cu.ft. per sec. q	Discharge Theoretical cu. ft. per sec. Q	Actual Av. Velocity ft. per sec. v	Coefficient of Discharge c	Coefficient of Loss n	Remarks
				6-in. x 22-1/2-in. Short Pipe Submerged 3 to 4 Diameters.					
				90° (1-3) Entrance Mouthpiece.					
1	0.0315	402	1.801	0.224	0.279	1.14	0.805	0.54	
2	0.0312	387	1.732	0.224	0.2775	1.14	0.807	0.53	
3	0.031	387	1.730	0.224	0.277	1.14	0.809	0.53	
4	0.0304	355	1.477	0.2205	0.2725	1.12	0.809	0.53	
5	0.0148	520	1.608	0.155	0.189	0.79	0.818	0.49	
6	0.0150	520	1.575	0.1517	0.1927	0.77	0.788	0.61	
7	0.015+	520	1.6005	0.1537	0.1927	0.78	0.798	0.56	
8	0.0150	582	1.782	0.1560	0.1927	0.79	0.811	0.51	
9	0.054	304	1.795	0.295	0.3680	1.50	0.803	0.55	
10	0.0545	3[illegible]5	1.780	0.292	0.3675	1.48	0.795	0.58	
11	0.053	322	1.862	0.2895	0.3620	1.47	0.800	0.56	
12	0.052	311	1.776	0.2855	0.358	1.45	0.797	0.56	
13	0.174	168	1.767	0.526	0.657	2.68	0.802	0.55	
14	0.1715	175	1.804	0.5155	0.6504	2.62	0.794	0.58	

Table 19.

Experimental Data with 6-in. and 3-in. Short Pipes with Inward Projecting Entrance.

Submerged 3 to 4 diameters.

1	2	3	4	5	6	7	8	9	10	11	12
Ref. No.	Difference in Hook Gage Headings ft. $h_3 - h_2$	Difference in Hook Gage Headings. ft. $h_3 - h_1$	Average Head ft. h	Time Sec. t	Rise in Pit ft. p	Discharge Actual cu.ft. per sec. q	Discharge Theoretical cu. ft.per sec. Q	Actual Av.Velocity ft.per sec. v	Coefficient of Discharge c	Coefficient of Loss m	Remarks.
					6 in. x 22-1/2 in. Short Pipe — Submerged 3 to 4 diameters.						
1		0.0155	0.0155	458	1.412	0.1540	0.1956	0.785	0.788+	0.61	
2		0.0155	0.0155	510	1.570	0.1541	0.1956	0.785	0.789	0.60	
3		0.0149	0.0149	540	1.595	0.1482	0.1920	0.755	0.773	0.66	
4		0.0153	0.0153	550	1.6485	0.1500	0.1945	0.765	0.772	0.66	
5		0.0150	0.0150	550	1.646	0.1497	0.1926	0.763	0.778	0.64	
6		0.0190-	0.0190-	437.5	1.481	0.1694	0.2165	0.864	0.782	0.63	
7		0.0190	0.0190	483	1.643	0.1704	0.2166	0.868	0.787	0.61	
8		0.0185	0.0185	484	1.629	0.1688	0.2140-	0.860	0.789	0.60	
9		0.0190	0.0190	485	1.6325	0.1680	0.2165	0.856	0.780	0.64	
10		0.0330	0.0330	386	1.725	0.2235	0.2860	1.14	0.783	0.62	
11		0.0324	0.0324	386	1.730	0.2240	0.2835	1.14	0.790	0.60	
12		0.0328	0.0328	401	1.7795	0.2221	0.2850	1.13	0.780	0.64	
13		0.0740	0.0740	300	1.9975	0.3330	0.4270	1.70	0.780	0.64	
14		0.0745	0.0745	254	1.7165	0.3370	0.4295	1.72	0.785	0.61	
15		0.0750	0.0750	270	1.817	0.3564	0.4310	1.71	0.782	0.63	
16		0.0745	0.0745	296	2.004	0.3380	0.4300	1.73	0.787	0.61	

1	2	3	4	5	6	7	8	9	10	11	12
17	0.4449	0.4458	0.4455	247	4.056	0.821	1.050	4.18	0.782	0.63	
18	0.4401	0.4401	0.4401	237	3.888	0.821	1.048	4.18	0.786	0.61	
19	0.4395	0.4417	0.4405	235	3.799	0.815	1.045	4.15	0.783	0.62	
		3 in. x 12 in. Short Pipe — Submerged about 5 diameters.									
20		0.1965	0.1965	698	1.776	0.1480	0.1875	2.81	0.790	0.600	
21		0.1960	0.1960	720	2.106	0.1462	0.1870	2.78	0.782	0.635	
22		0.502	0.502	561	2.665	0.237	0.299	4.50	0.794	0.585	
23		0.503	0.503	600	2.826	0.235+	0.300	4.46	0.786	0.610	
24		0.504	0.504	616	2.906	0.236	0.301	4.48	0.785	0.610	
		3 in. x 12 in. Short Pipe — Discharge in Air.									
25		1.93	1.93	253	2.138	0.459	0.587	8.70	0.780	0.64	
26		1.92	1.92	228	2.078	0.455	0.585	8.64	0.779	0.64	
27		1.885	1.885	240	2.162	0.452	0.582	8.56	0.776	0.665	
28		0.76	0.76	326	1.76	0.270	0.368	5.12	0.735	0.85	
29		0.764	0.764	337	1.82	0.270	0.370	5.12	0.730	0.87	

Table 20a.

Experimental Data with 6–in. x 22–1/2–in. Short Pipe having (1 – 2) Mouthpieces.

Submergence – 3 to 4 diameters.

1	2	3	4	5	6	7	8	9	10	11	12
Ref. No.	Difference in Hook Gage Headings. ft. $h_3 - h_2$	Difference in Hook Gage Headings. ft. $h_3 - h_1$	Average Head ft. h	Time Sec. t	Rise in Pit ft. p	Discharge Actual cu.ft. per sec. q	Discharge Theoretical cu. ft. per sec. Q	Actual Av. Velocity ft. per sec. v	Coefficient of Discharge c	Coefficient of Loss m	Remarks
					6–in. Pipe with 5°(1 –2) Entrance Mouthpiece..						
1		0.0335	0.0335	324	1.635	0.2520	0.2885	1.28	0.875	0.30	
2		0.0332	0.0332	366	1.843	0.2510	0.2870	1.28	0.876	0.30	
3		0.0330	0.0330	365	1.819	0.249	0.2865	1.27	0.871	0.32	
4		0.0326	0.0326	365	1.804	0.2475	0.2845	1.26	0.871	0.32	
5		0.0888	0.0888	233	1.996	0.428	0.469	2.19	0.914	0.20	
6		0.0888	0.0888	239	2.006	0.420	0.469	2.14	0.895	0.25	
7		0.0885	0.0855	233	1.957	0.418	0.467	2.13	0.895	0.25	
8		0.0875	0.0875	239	2.027	0.424	0.465	2.16	0.912	0.20	
9		0.2002	0.2002	153	1.836	0.600	0.704	3.06	0.853	0.37	
10		0.2005	0.2005	145	1.845	0.634	0.705	3.23	0.900	0.23	
11		0.1970	0.1970	147	1.770	0.603	0.698	3.07	0.854	0.37	
12		0.1955	0.1955	147	1.813	0.617	0.696	3.15	0.887	0.27	
13		0.1940	0.1940	147	1.806	0.614	0.693	3.12	0.886	0.27	
14	0.1761	0.1750	0.1756	262	3.103	0.593	0.659	3.02	0.900	0.23	
15	1.1693	0.1687	0.1690	349	4.023	0.576	0.647	2.94	0.890	0.26	
16	0.1678	0.1673	0.1676	331	3.704	0.560	0.644	2.86	0.870	0.32	

1	2	3	4	5	6	7	8	9	10	11	12
17	0.3488	0.3466	0.3477	250	4.159	0.8320	0.928	4.24	0.897	0.24	
18	0.3594	0.3520	0.3577	247	4.139	0.8375	0.939	4.26	0.893	0.25	
19	0.3521	0.3497	0.3509	232	3.926	0.8460	0.908	4.31	0.908	0.21	
			6–in. Pipe with 5°(1 – 2) Discharge Mouthpiece.								
20		0.0510	0.0510	260	1.883	0.362	0.355	1.84	1.020	–0.05	
21		0.0520	0.0520	284	1.897	0.334	0.3585	1.70	0.933	+0.15	
22		0.0490	0.0490	296	1.929	0.326	0.348	1.67	0.937	0.14	
23		0.0475	0.0475	296	1.893	0.3195	0.343	1.63	0.933	0.15	
24		0.0490	0.0490	295	1.959	0.331	0.342	1.69	0.950	0.11	
25	0.0606	0.0599	0.0602	495	3.868	0.391	0.386	1.99	1.012	–0.01	
26	0.0591	0.0584	0.0588	463	3.641	0.393	0.381	2.00	1.031	–0.05	
27	0.5865	0.5895	0.0588	488	3.741	0.384	0.381	1.96	1.008	–0.01	
28	0.0593	0.0596	0.0595	489	3.790	0.3875	0.384	1.97	1.010	–0.01	
29		0.1082	0.1082	183	1.996	0.544	0.517	2.77	1.05	–0.09	
30		0.1095	0.1095	185	1.892	0.512	0.520	2.60	0.985	+0.03	
31		0.1058	0.1058	190	1.902	0.500	0.511	2.55	0.978	+0.04	
32		0.103	0.103	194	1.910	0.491	0.505	2.50	0.974	+0.04	
33		0.105	0.105	193	1.874	0.486	0.510	2.48	0.954	+0.09	
34	0.1377	0.1364	0.1370	344	4.093	0.595	0.583	3.03	1.02	–0.05	
35	0.1429	0.1403	0.1416	325	3.839	0.590	0.592	3.00	0.998	0	
36	0.1406	0.1414	0.1410	333	3.994	0.5995	0.5905	3.06	1.015	–0.03	
			10°(1 – 2) Discharge End.								
37	0.039	0.039	0.039	455	2.635	0.290	0.310	1.48	0.934	0.15	
38	0.0365	0.0365	0.0365	467	2.692	0.288	0.300	1.47	0.960	0.08	
39	0.0369	0.0369	0.0369	422	2.440	0.289	0.302	1.47	0.956	0.09	
			15°(1 – 2) Entrance End.								
40	0.0611	0.0625	0.0618	425	3.056	0.368	0.359	1.88	0.940	0.13	

1	2	3	4	5	6	7	8	9	10	11	12
					15°(1 – 2) Entrance End. (Continued)						
41	0.0614	0.0632	0.0623	425	3.056	0.359	0.393	1.83	0.914	0.19	
42	0.0602	0.0613	0.0608	425	3.048	0.359	0.387	1.83	0.927	0.16	
43	0.0612	0.0621	0.0616	425	3.046	0.3585	0.390	1.83	0.920	0.18	
					30°(1 – 2) Entrance End.						
44	0.0815	0.0815	0.0815	410	3.400	0.414	0.449	2.11	0.922	0.17	
45	0.0817	0.0823	0.0820	376	3.099	0.412	0.450	2.10	0.915	0.19	
					30°(1 – 2) Discharge End.						
46	0.0841	0.0849	0.0845	426	3.041	0.357	0.457	1.82	0.782	0.63	
47	0.0820	0.0830	0.0825	426	3.066	0.360	0.452	1.84	0.796	0.58	
48	0.0817	0.0830	0.0823	426	3.067	0.360	0.452	1.84	0.796	0.58	
49	0.273	0.274	0.2698	270	3.542	0.656	0.817	3.34	0.803	0.55	
50	0.2731	0.2731	0.2731	270	3.560	0.660	0.882	3.36	0.803	0.55	
51	0.2687	0.2705	0.2696	270	3.536	0.655	0.817	3.34	0.802	0.55	
52		0.2735	0.2735	270	3.544	0.656	0.822	3.34	0.800	0.56	
					45°(1 – 2) Entrance End.						
53	0.046	0.047	0.0465	510	3.102	0.3045	0.339	1.55	0.899	0.23	
54	0.0460	0.0460	0.0460	570	3.469	0.304	0.337	1.55	0.904	0.22	
					45°(1 – 2) Discharge End.						
55		0.0540	0.0540	490	2.790	0.285	0.365	1.45	0.780	0.64	
56	0.0508	0.0512	0.0510	490	2.760	0.282	0.355	1.44	0.794	0.58	
57	0.0516	0.0524	0.0520	541	3.047	0.282	0.359	1.44	0.786	0.62	
58	0.0517	0.0510	0.0514	510	2.877	0.282	0.356	1.44	0.793	0.59	
					60°(1 – 2) Entrance End.						
59	0.080	0.080	0.080	475	3.75	0.395	0.445	2.02	0.889	0.26	

1	2	3	4	5	6	7	8	9	10	11	12
					60°(1 – 2) Entrance End. (Continued)						
60	0.0793	0.0793	0.0793	481	3.785	0.393	0.443	2.00	0.888	0.27	
					60°(1 – 2) Discharge End.						
61		0.104	0.104	420	3.348	0.398	0.507	2.03	0.786	0.62	
62	0.103	0.103	0.103	420	3.343	0.398	0.505	2.03	0.788	0.61	
63	0.261	0.260	0.2605	280	3.583	0.640	0.804	3.26	0.796	0.58	
64	0.261	0.260	0.2605	280	3.594	0.642	0.804	3.27	0.797	0.57	
65	0.1945	0.1935	0.194	320	3.53	0.550	0.693	2.80	0.794	0.58	
66	0.194	0.193	0.194	300	3.286	0.546	0.692	2.78	0.790	0.60	
67		0.0600	0.0600	510	3.091	0.303	0.386	1.55	0.786	0.62	
68		0.0595	0.0595	510	3.078	0.3015	0.384	1.54	0.786	0.62	
					20°(1 – 2) Entrance – 5°(1 – 2) Discharge.						
69	0.157	0.156	0.1565	210	3.506	0.836	0.623	4.26	1.34	–0.45	
70	0.156	0.157	0.1565	210	3.518	0.838	0.623	4.27	1.34	–0.45	
71		0.1515	0.1515	210	3.50	0.836	0.613	4.26	1.36	–0.46	
					30°(1 – 2) Entrance – 30°(1 – 2) Discharge.						
72	0.157	0.158	0.1575	320	3.751	0.586	0.625	2.99	0.938	0.14	
73	0.154	0.155	0.1545	300	3.504	0.584	0.620	2.98	0.941	0.13	
74	0.0715	0.0720	0.0718	420	3.323	0.395	0.421	2.01	0.940	0.13	
75	0.0712	0.0720	0.0716	480	3.835	0.399	0.425	2.03	0.948	0.11	
					30°(1 – 2) Entrance – 10°(1 – 2) Discharge.						
76	0.0228	0.0219	0.0223	460	2.644	0.287	0.235	1.46	1.25	–0.36	
77	0.024	0.023	0.0235	390	2.349	0.301	0.241	1.54	1.25	–0.36	

1	2	3	4	5	6	7	8	9	10	11	12
					45°(1 – 2) Entrance – 45°(1 – 2) Discharge.						
78	0.0516	0.0516	0.0516	435	2.850	0.327	0.357	1.67	0.917	0.19	
79	0.0535	0.0535	0.0535	479	3.166	0.350	0.364	1.68	0.907	0.21	

Table 20b.

Experimental Data with 6–in. x 22–1/2–in. Short Pipe having (1 – 3) and (1 – 4) Mouthpieces.

Submergence – 3 to 4 diameters.

1	2	3	4	5	6	7	8	9	10	11	12
Ref. No.	Difference in Hook Gage Headings. ft. $h_3 - h_2$	Difference in Hook Gage Headings. ft. $h_3 - h_1$	Average Head ft. h	Time Sec. t	Rise in Pit ft. p	Discharge Actual cu.ft. per sec. q	Discharge Theoretical cu. ft. per sec. Q	Actual Av. Velocity ft.per sec. v	Coefficient of Discharge c	Coefficient of Loss m	Remarks
					6–in. Pipe with 10°(1–3) Entrance Mouthpiece.						
1	0.0200	0.0215	0.0208	815	3.357	0.206	0.227	1.05	0.906	0.22	
2	0.0207	0.0227	0.0217	803	3.413	0.212	0.232	1.08	0.917	0.19	
3	0.0205	0.0212	0.0208	878	3.678	0.209	0.226	1.07	0.924	0.17	
4	0.0200	0.0212	0.0207	786	3.274	0.208	0.224	1.06	0.930	0.15	
5	0.0954	0.0970	0.0962	411	3.725	0.453	0.488	2.31	0.928	0.16	
6	0.0957	0.0971	0.0964	413	3.724	0.452	0.488	2.30	0.927	0.16	
7	0.0945	0.0962	0.0953	397	3.569	0.450	0.485	2.29	0.928	0.16	
					6–in. Pipe with 10°(1–3) Discharge Mouthpiece.						
8	0.0505	0.0513	0.0509	480	3.285	0.342	0.355	1.74	0.965	0.07	
9	0.0533	0.0548	0.0540	432	2.990	0.346	0.365	1.76	0.947	0.11	
10	0.0532	0.0541	0.0536	540	3.756	0.347	0.364	1.77	0.955	0.09	
11	0.194	0.193	0.1935	253	3.475	0.687	0.692	3.50	0.993	0.01	
12	0.1965	0.1962	0.1964	268	3.671	0.685	0.697	3.49	0.984	0.03	
13	0.1837	0.1870	0.1853	281	3.870	0.688	0.677	3.51	1.015	0.03	
14	0.1895	0.1935	0.1912	309	4.080	0.663	0.687	3.38	0.966	0.07	
15	0.1835	0.1862	0.1848	284	3.740	0.658	0.677	3.36	0.973	0.05	

1	2	3	4	5	6	7	8	9	10	11	12
					6–in. Pipe with 10°(1–3) Discharge Mouthpiece.						
16	0.0965	0.0955	0.096	340	3.174	0.467	0.487	2.38	0.958	0.09	
17	0.1005	0.1005	0.1005	370	3.480	0.471	0.499	2.40	0.945	0.12	
18				372	3.486.	0.468	0.502	2.39	0.933	0.15	
19	0.037	0.037	0.037	544	3.174	0.292	0.303	1.49	0.964	0.08	
20		0.038	0.038	527	3.065	0.291	0.307	1.48	0.946	0.12	
21		0.0368	0.0368	439	2.545	0.290	0.302	1.48	0.960	0.08	
					6–in. Pipe with 15°(1–3) Entrance Mouthpiece.						
22	0.0502	0.0510	0.0506	425	2.730	0.321	0.354	1.64	0.907	0.21	
23	0.0496	0.0510	0.0503	487	3.131	0.326	0.353	1.66	0.924	0.17	
24	0.0480	0.0492	0.0486	488	3.151	0.322	0.347	1.64	0.930	0.15	
25	0.0487	0.0500	0.0493	489	3.165	0.324	0.349	1.65	0.928	0.16	
26	0.1915	0.1927	0.1921	261	3.332	0.638	0.690	3.25	0.926	0.16	
27	0.1915	0.1925	0.192	270	3.424	0.635	0.690	3.24	0.920	0.18	
28	0.1935	0.1945	0.194	258	3.294	0.638	0.687	3.25	0.921	0.18	
29	0.190	0.1905	0.1902	258	3.287	0.637	0.687	3.25	0.927	0.18	
30	0.1912	0.1915	0.1914	266	3.314	0.621	0.686	3.17	0.902	0.23	
31	0.1925	0.1931	0.1928	287	3.595	0.626	0.691	3.14	0.906	0.22	
					6–in. Pipe with 15°(1–3) Discharge Mouthpiece.						
32	0.060	0.059	0.0596	440	3.030	0.344	0.384	1.76	0.897	0.24	
33	0.0582	0.0582	0.0582	465	3.196	0.343	0.380	1.75	0.904	0.22	
34	0.195	0.194	0.1945	269	3.426	0.637	0.694	3.25	0.917	0.19	
35	0.1946	0.1946	0.1946	270	3.410	0.632	0.694	3.22	0.909	0.21	
36	0.189	0.188	0.1885	286	3.60	0.629	0.685	3.20	0.920	0.18	

1	2	3	4	5	6	7	8	9	10	11	12
37				6–in. Pipe with 20°(1–3) Entrance Mouthpiece.							
37	0.101	0.101	0.1010	330	3.058	0.463	0.500	2.36	0.926	0.16	
38	0.101	0.1015	0.1015	360	3.335	0.463	0.500	2.36	0.927	0.16	
39	0.1005	0.101	0.1008	361	3.313	0.458	0.499	2.34	0.920	0.18	
40	0.102	0.1015	0.1018	330	3.050	0.462	0.500	2.36	0.924	0.17	
				6–in. Pipe with 20°(1–3) Discharge Mouthpiece.							
41	0.043	0.043	0.043	450	2.571	0.285	0.327	1.45	0.874	0.21	
42	0.044	0.044	0.044	430	2.465	0.286	0.330	1.46	0.870	0.22	
43											
43	0.222	0.219	0.2205	231	3.035	0.657	0.740	3.35	0.889	0.26	
44	0.2186	0.2186	0.2186	257	3.385	0.660	0.737	3.36	0.895	0.24	
				6–in. Pipe with 45°(1–3) Entrance Mouthpiece.							
45	0.116	0.1178	0.1170	360	3.466	0.482	0.538	2.46	0.895	0.24	
46	0.1137	0.1155	0.1146	360	3.632	0.504	0.553	2.57	0.945	0.12	
47	0.114	0.115	0.1145	360	3.432	0.476	0.533	2.43	0.895	0.24	
48	0.1155	0.1165	0.1160	360	3.669	0.509	0.535	2.60	0.950	0.11	
49	0.1175	0.118	0.1178	360	3.480	0.4835	0.539	2.46	0.898	0.24	
50	0.1185	0.119	0.1187	360	3.509	0.4875	0.542	2.48	0.900	0.23	
51	0.115	0.117	0.1160	360	3.474	0.482	0.535	2.46	0.901	0.23	
52	0.3218	0.3220	0.3219	210	3.399	0.810	0.894	4.13	0.906	0.21	
53	0.3212	0.3226	0.3226	210	3.400	0.810	0.895	4.13	0.906	0.21	
54	0.324	0.326	0.3225	211	3.420	0.815	0.898	4.15	0.907	0.21	
				6–in. Pipe with 20°(1–3) Entrance – 15°(1–3) Discharge.							
55	0.201	0.202	0.2015	240	3.927	0.818	0.706	4.17	1.158	0.26	
56	0.205	0.203	0.204	240	3.927	0.818	0.710	4.17	1.15	0.25	
57	0.199	0.204	0.201	240	3.921	0.817	0.706	4.17	1.155	0.25	

1	2	3	4	5	6	7	8	9	10	11	12
					20° (1–4) Entrance Mouthpiece.						
58	0.189	0.191	0.190	266	3.391	0.637	0.686	3.25	0.928	0.16	
59	0.191	0.1908	0.1909	281	3.539	0.630	0.688	3.21	0.914	0.20	
60	0.190	0.191	0.1905	265	3.579	0.675	0.687	3.44	0.983	0.03	
61	0.192	0.1917	0.1918	276	3.575	0.648	0.689	3.30	0.940	0.13	
62	0.1884	0.1886	0.1885	292	3.716	0.636	9.683	3.24	0.932	0.15	
63	0.187	0.188	0.1875	285	3.811	0.668	0.682	3.41	0.981	0.04	
64	0.1843	0.1851	0.1847	288	3.616	0.627	0.676	3.20	0.928	0.16	

22. Results of Earlier Experimenters on Orifices.— Table 22 gives the results of experiments by Hamilton Smith, Jr. with vertical submerged orifices allowing complete contraction. The quantity of flow was measured volumetrically. The value of the coefficient of discharge, c, for each case is the mean from several experiments with nearly identical heads.

Hook gages were used to determine the level of the water surface in each tank. The depth of submergence varied from 0.57 ft. to 0.73 ft.

The author states that for the 0.05-ft. round and the 0.05-ft. by 0.05-ft. square, but particularly for the 0.05-ft. by 0.3-ft. rectangular orifice, the comparatively long diverging sides (0.021 ft. being the full thickness of the plate) appreciably increased the discharge for a head of two feet or more. In the experiments herein recorded the effect of mouthpieces seems as marked at low heads as at medium heads. The values from the curve given by Smith showing high values of c for the lower heads are inconsistent also with the results obtained in the present experiments.

Table 21.

Francis — Coefficients of Discharge for a Circular Vertical Submerged Orifice with Full Contraction.

Diameter — 0.1018 feet.

h — ft.	c
0.092	0.564
0.435	0.563
0.484	0.580
0.776	0.587
1.024	0.592
1.324	0.592
1.490	0.592
1.499	0.593
1.514	0.591

Table 21 gives values for the experiments by Francis.

Table ~~22~~.

H. Smith, Jr.

Coefficients of Discharge for Vertical Submerged Orifices with Full Contraction.

Circular Diam. = 0.6 in.		Circular Diam. = 1.2 in.		Square 0.6 in. x 0.6 in.		Square 1.2 in. x 1.2 in.		Rectangular 3.6 in. x 0.6 in.	
h	c	h	c	h	c	h	c	h	c
0.437	0.6183	0.250	0.6048	0.35	0.6201	0.207	0.6117	0.614	0.6219
2.16	0.6041	0.648	0.6027	2.21	0.6092	0.410	0.6091	1.63	0.6207
4.08	0.6016	0.985	0.6025	4.06	0.6068	0.771	0.6053	2.77	0.6188
		1.51	0.6006			1.52	0.6055		
		2.00	0.6006			2.32	0.6040		
		2.58	0.5997			3.11	0.6052		
		2.99	0.5989			3.95	0.6048		
		3.57	0.5987						
		3.97	0.5992						

Taking the mean of the coefficients, for heads greater than 1 foot, gives c = 0.592.

The quantity discharged was measured over a weir, the heads on which were very small varying from 0.0293 ft. to 0.0778 ft., corresponding to the heads h = 0.0916 ft. to h = 1.514 ft. The chance for error, therefore, was considerable. The low values obtained must carry much less weight than most of the values obtained in other tests. The great variation in c with the head in the light of the experiments herein recorded also indicates inaccuracy in results.

Table ~~23.~~

Ellis – Coefficients of Discharge for Horizontal Submerged Orifices with Full Contraction.

Circular Diam. = 1 ft.		Square 1 ft. by 1 ft.	
Head ft. h	Coefficient Discharge c	Head ft. h	Coefficient Discharge c
2.60	0.607	2.32	0.600
4.71	0.590	3.92	0.602
6.41	0.606	7.99	0.606
8.10	0.599	11.58	0.605
8.80	0.600	14.31	0.611
12.09	0.600	16.22	0.606
14.25	0.601	18.45	0.606
16.29	0.602		
18.66	0.599		

Table 23, gives the results of the experiments of T. G. Ellis. Each value of c is the average of from 5 to 15 experiments at approximately the same head.

Discharge was measured over a weir, the head on which was determined by means of a tube placed very near the inner face of the weir. However, since the velocity of approach was small, the error from the cause is probably small. Francis' weir formula was used.

There were no heads upon the weir less than 0.28 ft., and but very few less than 0.5 ft. The proportion of length and depth were such as to make Francis' weir formula applicable.

Table 24: Balch – Coefficients of Discharge for Vertical Submerged Orifices with Full Contraction.

Circular Diam. = 1 ft.		Square 1 ft. by 1 ft.	
Head ft. h	Coefficient Discharge c	Head ft. h	Coefficient Discharge c
0.145	0.5909	0.363	0.5940
0.469	0.5902	0.750	0.5940
0.851	0.5912	0.771	0.5932
1.254	0.5893	0.826	0.5982
1.612	0.5921	0.805	0.5950
2.012	0.5924	1.134	0.5960
2.421	0.5954	1.371	0.5970
2.949	0.5967	2.097	0.6056
3.410	0.6006	2.636	0.6105
4.015	0.6054	3.220	0.6095
		3.975	0.6148

Table 24 gives the results of the experiments by L. R. Balch.

The head, h, causing flow was measured by means of two glass tube gages, one on each side of the partition which contained the orifice plate and which separated the two tanks, h being the difference in the gage readings. Each gage was read by estimating to 0.001 ft.

The discharge was measured over a 12–in. rectangular weir which previously had been calibrated.

Davis and Balch found the values given below for a submerged square orifice 1 ft. – 6–1/8 in. on each side, the length or thickness being 6 in. While this is not a thin edged orifice the length or thickness is not sufficient to cause it to act as a short pipe or tube, although contraction is somewhat suppressed. The values

for c show a marked increase with a comparatively small increase in head.

Table 25.

Head ft. h	Coefficient Discharge c
0.135	0.615
0.316	0.631
0.540	0.641
0.704	0.647
0.862	0.663
0.794	0.659
0.620	0.644
0.446	0.633
0.219	0.610
0.146	0.603

Table 26.

Stewart – Coefficients of Discharge and Loss for a Wooden Submerged Orifice 4 ft. Square. Contraction Somewhat Suppressed.

Head ft. h	Coefficient of Discharge c	Coefficient of Loss m	
0.05	0.626	2.55	
0.10	0.608	2.70	
0.15	0.605	2.73	
0.20	0.605	2.73	
0.25	0.606	2.72	
0.30	0.610	2.69	
0.05 to 0.30	0.610	2.68	Average Values.

Table 26 gives values obtained with a short tube 0.031 ft. long (see Table 32). While the $\frac{l}{d} = 0.077$ is very small, without doubt, the value of c is larger than would be obtained with a sharp edged orifice.

23. Results of Earlier Experimenters on Mouthpieces.— The values in Table 27 were obtained with mouthpieces as shown in Fig. 29

Table 27.
Castel – D'Aubuissson — Conical Converging Mouthpieces Discharging into Air
Flush Entrance.

Length = 0.131 ft. (1.57 in) d = 0.05 ft. (.6 in)				Length = 0.164 ft. (1.97 in) d = 0.066 ft. (.792 in)			
α	c	α	c	α	c	α	c
0	0.829	16° 36'	0.938	2° 50'	0.914	13° 40'	0.956
1° 36'	0.866	19° 28'	0.924	5° 26'	0.930	15° 2'	0.949
3° 10'	0.895	23° 00'	0.914	6° 54'	0.938	18° 10'	0.939
4° 10'	0.912	30° 00'	0.895	10° 30'	0.945	23° 4'	0.930
5° 26'	0.924	40° 20'	0.870	12° 10''	0.950	35° 52'	0.920
7° 52'	0.930	48° 50'	0.847	Length = 0.328 ft. (3.94 in) d = 0.066 ft.			
13° 24'	0.946			α	c	α	c
				11° 52'	0.965	16° 54'	0.952
				14° 12'	0.958		

Heads employed varied, for each given experiment, from 9.84 ft. to 0.66 ft., but there was only a very slight difference in the value of c with varying values of the head for the same mouthpiece.

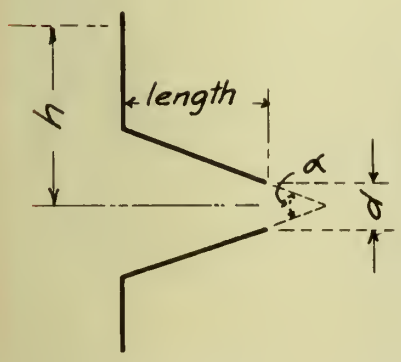

Fig. 29.

The mouthpieces were of smooth polished metal. The quantity discharged was measured volumetrically. According to this table the coefficient of discharge attains its maximum value of 0.946 for a mouthpiece whose sides converge at an angle of 13–1/2° although the coefficient of velocity increases continually with the angle of convergence.

Wiesbach formed a circular orifice in a vertical wall 0.0165 ft. thick, shaped as nearly as possible to the form of a jet from an orifice in a thin wall.

For such an orifice discharging into air with the outlet diameter = 0.033 ft. he found the following coefficients of discharge:

Table 28.

h, ft.	c
0.066	0.959
1.64	0.967
11.48	0.975
55.77	0.994
328.00	0.994

Ellis formed a wooden mouthpiece on a square horizontal orifice, each side of approach being a quarter ellipse with semidiameters 0.5 ft. (vertical) and 0.33 ft. (horizontal). The discharge section (orifice) was 1 ft. square. The following values were obtained with submerged discharge

Table 29.

h. ft.	c
3.0416	0.9512
3.0733	0.9523
5.7593	0.9453
5.7790	0.9452
5.7630	0.9460
10.5398	0.9425
10.6035	0.9436
13.5709	0.9434
18.2263	0.9437
18.2180	0.9436

By setting the mouthpiece shown in Fig. 30 in a pipe and measuring the pressure on each side, Brownlee found the following values for the coefficient of discharge taking the head as the difference

in pressures on the two sides of the mouth-piece.

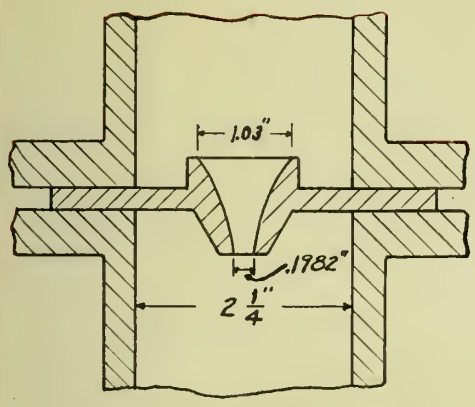

Fig. 30.

Table 30

Head ft. h	Actual Average Velocity ft. per sec. v	Coefficient of Discharge c
1	7.55	0.941
2	10.73	0.946
4	15.39	0.959
6	18.9	0.961
8	21.85	0.963
10	24.49	0.965
12-1/2	27.4	0.966

Table 31
Stewart — Coefficients of Discharge for an Elliptical Entrance Mouthpiece on Wooden Submerged 4-ft. x 4-ft. Square Tubes of Various Lengths.

Head ft.	Length in Feet.				
	0.31	2.50	5.00	10.0	14.0
0.05	0.934	0.928	0.925	0.913	0.917
0.10	0.919	0.899	0.887	0.880	0.881
0.15	0.924	0.898	0.888	0.882	0.883
0.20	0.936	0.911	0.900	0.895	0.894
0.25	0.953	0.926	0.917		
0.30	0.968				

Francis found the following coefficients of discharge for a submerged cycloidal mouthpiece — Part A, Fig. 33.

Head ft. h	Actual Average Velocity ft. per sec. v	Coefficient of Discharge c
0.034 to 1.52	1.20 to 9.32	0.815 to 0.944

Eighteen experiments were run and c showed a rather gradual increase with the head. The wide range in the value of c, no doubt,

is due to error in determining the discharge over a weir at very low heads (see Table 36).

The value of c = 0.942 for heads greater than 1.5 ft. corresponds closely with the maximum value, c = 0.946, found by Castel for the smallest discharge area (diam. 0.05 ft.) of his conical mouthpieces with angle $\alpha = 13° 24'$.

Francis states that when the discharge was into air, Michelotti in one of his experiments by employing a cycloidal tube found c = 0.983. Eytelwein found c = 0.980. Other experimenters have found 0.96 to 0.98.

Weisbach found with the divergent mouthpiece shown in Fig. 31 the value c = 0.946 for heads varying from 0.82 to 10.82 ft., calculation being based on the smallest area.

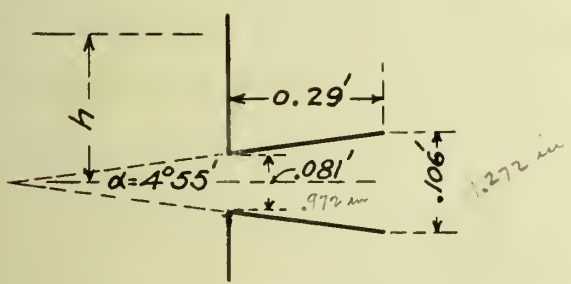

Fig. 31

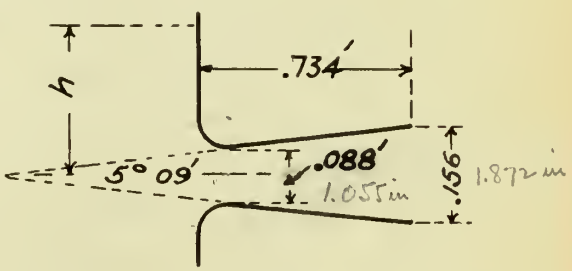

Fig. 32.

Eytelwein found with the divergent mouthpiece with rounded entrance (Fig. 32) c = 1.55, the smallest area being used in calculating the theoretical discharge.

Freeman's experiments on smooth nozzles, with velocity of approach gave the following values:

h ft.	c
120.1	0.987
119.7	0.985
46.7	0.990

24. Results of Earlier Experimenters on Short Pipes with Entrance Flush.— D'Aubuisson gives the following values of c as deduced by the authorities named. Water Discharged into air.

Table 32.

Authority	Diameter ft.	l ft.	h ft.	c
Castel	0.051	0.131	0.66	0.827
"	0.051	0.131	1.58	0.829
"	0.151	0.131	3.2	0.829
"	0.151	0.131	6.6	0.829
"	0.151	0.131	9.9	0.830
Eytelwein	0.085	0.256	2.4	0.821
Venturi	0.134	0.420	2.9	0.822
Michelotti	0.266	0.709	7.1	0.815
	Square Side-ft.			
"	0.266	0.709	12.5	0.803
"	0.266	0.709	22.0	0.803

Weisbach gave the following values of the Coefficient of Discharge for tubes three diameters in length under heads 0.75 to 1.97 ft. as follows:

Diameter (ft)	0.033	0.066	0.098	0.131
c	0.84	0.83	0.82	0.81

Weisbach states that Buff found, with a tube 2.79 lines wide and 4.3 lines long, that c increased from 0.825 to 0.855 when the head decreased from 33 to 1-1/2 inches.

Table 33 gives the results obtained by Bossut.

The pipes were of well polished copper, of true cylindrical form. In determining the coefficient of discharge, Bossut measured h from the discharge end of the pipe. The results are smaller than given by other experimenters. Taking the head to the entrance of pipe gives c_t as computed by H. Smith. This head corresponds to the head which should be used if pipe were horizontal. There seems little justification for this however. In the light of the experi-

Table 33.

Bossut. — Flow through Vertical Cylindrical Pipes with End Flush.
Lower End Flowing Full — Discharge into Air.

Head from Surface to Lower End of Pipe ft.	Length of Pipe ft.	Diameter of Pipe ft.	$\frac{l}{d}$	Average Velocity through Pipe ft. per Sec.	Coefficient of Discharge	Coefficient of Discharge taking h to Entrance of Pipe
h	l	d		v	c	c_t
12.862	0.355	0.0888	4	23.13	0.804	0.816
12.684	0.177	0.0888	2	22.97	0.804	0.810
12.640	0.133	0.0888	1.5	22.94	0.804	0.809
4.085	0.177	0.0444	4		0.785	0.803
4.085	0.177	0.0740	2.4	12.76	0.787	0.805
2.131	0.177	0.0444	4	9.21	0.786	0.821
2.131	0.177	0.0740	2.4	9.23	0.789	0.824

ments herein recorded these values do not seem so low. From the experiments Bossut deduces a table showing the discharge through a cylindrical pipe, with a diameter of 0.089 ft. and a length of 0.178 ft. under a head from 1.07 to 16.0 ft. showing c to vary gradually from 0.8055 for the least head to 0.8005 for the largest head.

Table 34.
Stewart — Values of Coefficients of Discharge for Submerged Square Wooden Horizontal Tubes of Various Lengths, 4 ft. Square, with Entrance Flush

Head ft, h.	Length of Tube in Feet. 0.31 $\frac{l}{d}$ =0.077	0.62 =0.165	1.25 =0.33	2.50 =0.66	5.00 =1.25	10.00 = 2.5	14.00 = 3.5
0.05	0.626	0.645	0.666	0.761	0.797	0.814	0.786
0.10	0.608	0.626	0.642	0.712	0.755	0.772	0.786
0.15	0.605	0.624	0.639	0.702	0.751	0.771	0.786
0.20	0.605	0.626	0.642	0.705	0.761	0.786	0.801
0.25	0.606	0.630	0.648	0.714	0.775	0.804	0.820
0.30	0.610	0.635	0.656	0.725	0.789	0.824	0.841

Table 34 gives the coefficients of discharge obtained by

Stewart on a submerged tube 4 ft. square.
The velocity varied from 1 to 4 ft. per second.

For the tube 5 ft. long or longer the discharge end flowed full while for l = 1.25 ft. and l = 2.50 ft., the discharge end did not flow full even though submerged. A current flowed up stream in the upper part of the tube, showing the effect of gravity under low heads.

Table 35

Balch — Values of Coefficients of Discharge for 4-in. Diameter Submerged Short Pipes with Flush Entrance.

Length in.	Head ft.	Coefficient of Discharge Range	Coefficient of Discharge Average
1.0 $\frac{l}{d} = \frac{1}{4}$	0.304 to 3.900	0.5983 to 0.615	0.607
2.0 $\frac{l}{d} = 0.5$	0.172 to 3.995	0.6348 to 0.6707	0.649
4.0 $\frac{l}{d} = 1.0$	0.557 to 1.003	0.7513 to 0.7874	0.768
6.0 $\frac{l}{d} = 1.5$	0.390 to 3.881	0.7817 to 0.8170	0.797

The results show no uniform or consistent variation with the head. From the results given in Table 38 for $\frac{l}{d} = 2.5$ or 3.0 the Coefficient of Discharge would be slightly greater than for $\frac{l}{d} = 1.5$.

25.Results of Earlier Experimenters with Short Pipes with Inward Projecting Entrance.— Experiments by H.J.I.Bilton give the following values of the Coefficient of Discharge for cylindrical pipes discharging in atmosphere with heads from 0.5 ft. upwards; upper limit not stated although the heads used in the case of orifices reported in the same paper varied from 2 in. to 100 in. The length of the tube in every case was 2–1/2 diameters.

Diameter in inches	Coefficient of Discharge
1/8	0.91
1/4	0.87
3/8	0.85
1/2	0.83
3/4	0.81
1	0.79
1–1/2	0.77
2	0.76
2–1/2	0.75

"Bidone with a circular pipe of 0.13 ft. diameter and length 0.22 ft.($\frac{l}{d}$ = 1.7) when discharging into air found c to be 0.767.

"Weisbach found in a similar case a value of 0.71."

26.Results of Earlier Experimenters on Combination of Entrance and Discharge Mouthpieces. — Francis' values obtained on the tube

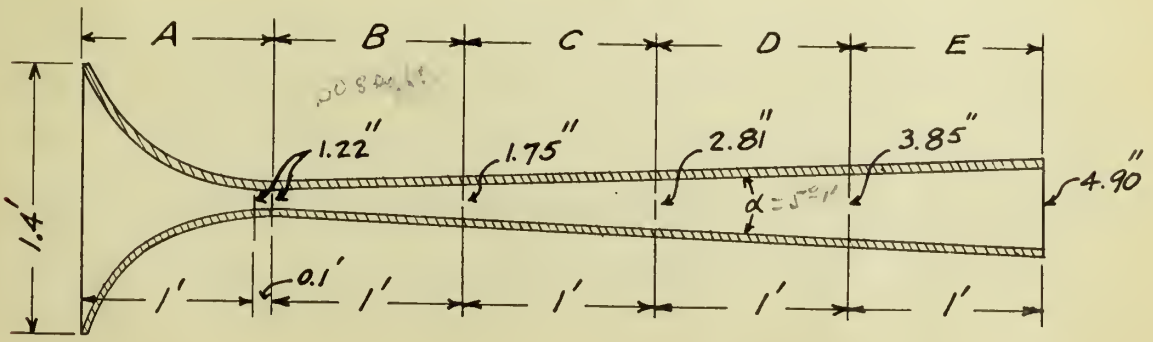

Fig. 55. Compound Tube used by Francis.
Angle of Divergence, 5°–1'.

shown in Fig. 33 found values as given in Table 36 for submerged discharge. The discharge was measured over a weir some of the heads on which were so small as to make appreciable errors very probable. Table 36 includes only values as given by H. Smith, Jr., for which the head on the weir is greater than o.07. The coeffi-cient of discharge is based on the smallest area, 0.00806 sq. ft.

Table 36

Francis — Flow through Submerged Compound Tubes.

Part Used	h ft.	c	Part Used	h ft.	c	Part Used	h ft.	c
A	0.53	0.927	ABC	0.14	1.98	ABCD	1.18	2.43
A	0.78	0.935	ABC	0.21	2.03	ABCD	1.36	2.43
A	0.98	0.928	ABC	0.31	2.07	ABCD	1.39	2.26
A	1.23	0.933	ABC	0.50	2.12			
A	1.40	0.937	ABC	0.71	2.15			
A	1.52	0.944	ABC	1.10	2.16			
			ABC	1.31	2.12			
AB	0.20	1.48	ABCD	0.13	2.08	ABCDE	0.11	2.05
AB	0.30	1.51	ABCD	0.27	2.25	ABCDE	0.15	2.11
AB	0.40	1.54	ABCD	0.44	2.26	ABCDE	0.21	2.17
AB	0.85	1.59	ABCD	0.63	2.30	ABCDE	0.31	2.26
AB	1.45	1.60	ABCD	0.92	2.38	ABCDE	0.42	2.31
AB	1.47	1.57				ABCDE	0.64	2.30
						ABCDE	0.96	2.31
						ABCDE	1.29	2.39
						ABCDE	1.36	2.33
						ABCDE	1.41	2.25

The results obtained by Brownlee with the tube shown in Fig. 34 are given in Table 37. This tube was placed inside of a 2.25 in. pipe and the head taken as the difference in the pressures as measured on each side of the pipe. It is doubtful if the same results would be obtained with an arrangement like that of Francis. The results herein recorded indicate this.

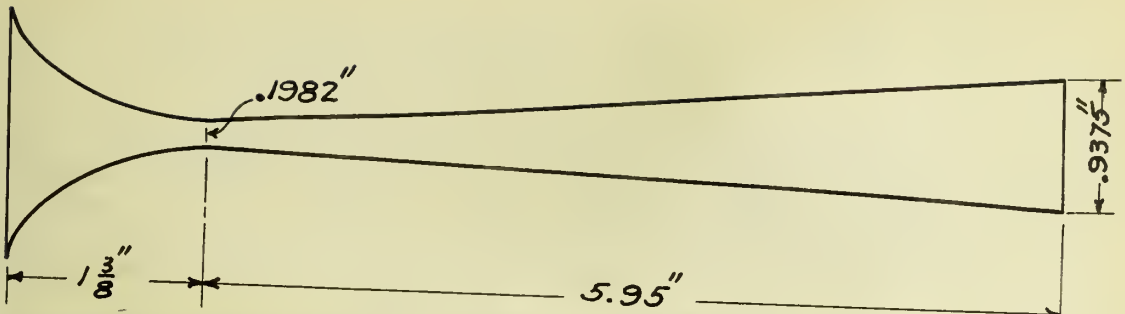

Fig.34 – Compound Tube Used by Brownlee – Angle of Divergence about 7°–5'.

Table 37.

Brownlee — Flow through a Submerged Compound Tube.

h ft.	Actual velocity ft. per Sec.	c
0.25	6.66	1.66
0.50	10.23	1.50
0.75	13.6	1.96
1.00	16.34	2.04
2.00	27.74	2.18
3.00	31.95	2.30
4.00	37.90	2.36
5.00	43.45	2.42
6.00	48.14	2.45

Venturi experimented on many forms of diverging tubes, the maximum increase of velocity was obtained with a conical tube in which the sides diverged from each other at an angle of 4° 27'. Attaching an entrance mouthpiece having nearly the form of the contracted vein, the velocity was increased in the ratio of 1 to 2., the discharge end flowing full in each case and discharging into air.

Eytelwein made some similar experiments with a mouthpiece and a tube whose sides diverged at an angle of 5° 9'. He found that the velocity was increased in the ratio of 1 to 1.69

Table 38 gives the values obtained by Stewart with a 4–ft. square submerged wooden tube of various lengths and with entrance

Table 38

Stewart — Values of the Coefficient of Discharge for Flow through Horizontal Submerged Tube 4.0 feet square.

Head ft. h	Forms of Entrance and Outlet.	Length of Tube in Feet. 0.31	0.62	1.25	2.50	5.00	10.0	14.0
		Values of the Coefficient, c.						
0.05	Square Corners	0.626	0.645	0.666	0.761	0.797	0.814	0.828
	a	0.666			0.755	0.801		0.837
	b	0.733			0.761	0.822		0.851
	c	0.823			0.761	0.863		0.877
	c							0.873
	d	0.931			0.928	0.925	0.913	0.917
0.10	Square Corners	0.608	0.626	0.642	0.712	0.755	0.772	0.786
	a	0.631			0.692	0.763		0.792
	b	0.679			0.712	0.783		0.804
	c	0.764			0.712	0.818		0.831
	c							0.820
	d	0.919			0.899	0.887	0.880	0.881
0.15	Square Corners	0.605	0.624	0.639	0.702	0.751	0.771	0.786
	a	0.626			0.683	0.760		0.795
	b	0.672			0.702	0.779		0.805
	c	0.758			0.702	0.8 9		0.830
	c							0.820
	d	0.924			0.898	0.888	0.882	0.883
0.20	Square Corners	0.605	0.626	0.642	0.705	0.761	0.786	0.801
	a	0.628			0.689	0.770		0.811
	b	0.673			0.705	0.783		0.824
	c	0.764			0.705	0.820		0.846
	c							0.837
	d	0.936			0.911	0.900	0.895	0.894
0.25	Square Corners	0.606	0.630	0.648	0.714	0.775	0.804	0.820
	a	0.630			0.700	0.783		
	b	0.678			0.714	0.801		
	c	0.772			0.714	0.845		
	c							
	d	0.953			0.926	0.917		
0.30	Square Corners	0.610	0.635	0.656	0.275	0.789	0.824	0.841
	a	0.635						
	b	0.684						
	c	0.781						
	c							
	d	0.968						

Forms of Entrance and Outlet Used for Tubes in Table Continued on Next Sheet.

Forms of Entrance and Outlet Used for Tubes in Table 3

Square Corners:- Entrance: all corners, 90° - Flush.
Outlet: tube projecting into water on down stream side of bulkhead.

a:- Entrance: contraction suppressed on bottom.
Outlet: tube projecting into water on down stream side of bulkhead.

b:- Entrance: contraction suppressed on bottom and one side.
Outlet: tube projecting into water on down stream side of bulkhead.

c:- Entrance: contraction suppressed on bottom and two sides.
Outlet: tube projecting into water on down stream side of bulkhead.

c':-Entrance: contraction suppressed on bottom and two sides.
Outlet: square corners with bulkhead to sides of channel preventing the return current along the sides of the tube.

d:- Entrance: contraction suppressed on bottom, two sides and top.
Outlet: tube projecting into water on down stream side of bulkhead.

suppressed on one or more sides by means of wooden curved approaches, elliptical in form. The curves of the ellipse had semi-axes of 3 ft. and 2 ft. Hence, in the case of a complete entrance mouthpiece (entrance suppressed on all four edges) the outer area is 8 ft. square in a plane 3 ft. from the entrance to the 4 ft. tube.

Table 39

Balch — Flow through Submerged Cylindrical Tubes 4 in. in Diameter with Bevelled Entrance.

Entrance Bevel	Length in.	Head ft.	Coefficient of Discharge		Ratio of Area of Tube to Outer Area of Bevel.
			Range	Average	
1/2" x 1/2"	1.0 $\frac{l}{d} = 0.25$	0.428 to 2.435	0.7137 to 0.7475	0.7311	1 to 1.56
3/4" x 3/4"	2.0 $\frac{l}{d} = 0.50$	0.463 to 4.08	0.8203 to 0.8741	0.863	1 to 1.9
3/4" x 3/4"	4.0 $\frac{l}{d} = 1.0$	0.314 to 4.045	0.8964 to 0.9327	0.9153	"
3/4" x 3/4"	6.0 $\frac{l}{d} = 1.5$	0.3745 to 3.960	0.9104 to 0.9260	0.922	"

Table 39 shows the results obtained by Balch.

There was no uniform or consistent increase in c as the head increased although the values of c are in most cases smaller for $h < 1.5$ ft. than for $h > 1.5$ ft. The values of c remain almost constant for $h > 1.5$ ft. and are slightly greater than the average of all the values as given in the above table.

Davis and Balch, with the mouthpieces and tubes shown in Fig. 35, 36, and 37 obtained results as given in the following tables, c being taken as an average for heads of nearly the same value.

Table 40

Tube as Shown in Fig.
12 Experiments.

h ft.	c
0.114	0.829
0.170	0.867
0.228	0.849
0.299	0.846
0.393	0.877
0.511	0.894
0.612	0.940
0.748	0.955

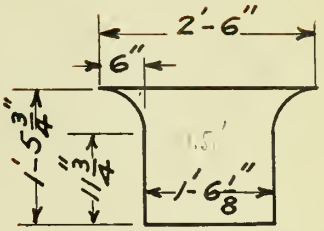

Fig. 35. Square Tube

Table 41
Tube as Shown in Fig.
29 Experiments.

h ft.	c
0.061	0.889
0.100	0.931
0.165	0.866
0.233	0.971
0.276	0.948
0.308	0.994
0.341	0.968
0.380	1.03
0.404	1.00
0.480	1.02
0.549	1.06

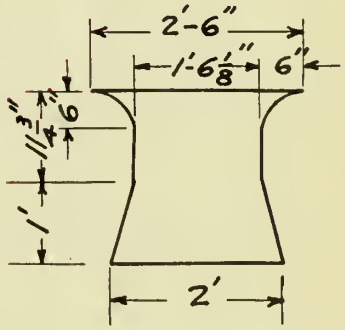

Fig. 36. Square Tube

Table 42
Tube as Shown in Fig.
17 Experiments.

h ft.	c
0.095	0.965
0.146	0.974
0.220	1.017
0.309	0.987
0.374	1.015
0.461	1.000

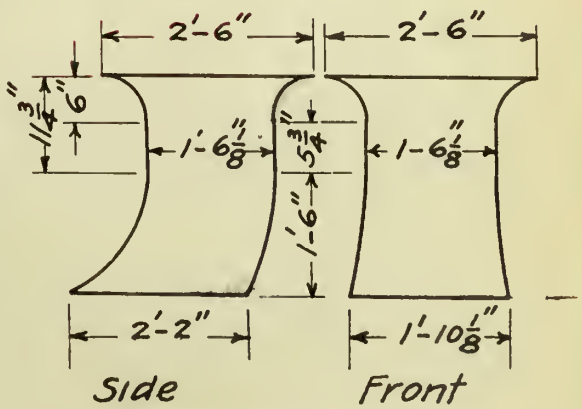

Fig. 37. Square Tube

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